CHAPTER 9. OPPORTUNITIES FOR INCREASING PRODUCTIVITY ON TIMBERLANDS

Existing timberlands have the potential to produce much larger quantities of timber, with positive economic returns, than they do today. In addition, in some regions there are large areas only marginally productive in crop or pasture use that would be suitable for growing trees. Only a part of this potential increase in productivity on timberlands is reflected in the projections discussed earlier. If more of the opportunities to increase timber supplies were used, it would be possible to produce greater quantities of timber products at lower costs. Achieving this increase in productivity would require time and substantial investments in a variety of research, forest management, and landowner assistance programs. It would also require accommodation of timber production and other benefits derived from timberland, such as recreation, wildlife habitat, and water quality.

This chapter takes a look at several measures of the productivity of the Nation's timberlands over the past three and a half decades. It reviews recent trends in research and timber management activities that have increased the productivity of timberlands, and it quantifies the opportunities that currently exist to achieve further increases in timber growth through investments in forest management on private lands other than forest industry lands. Finally, it discusses some of the policies and programs that have encouraged investments in timber management by private owners in the past and some of the economic and institutional factors that could determine whether the needed investments are made in the future. The following chapter will review other means to increase timber supplies and improve productivity in forestry by increasing the efficiency of harvesting, processing, and end use of timber.

FOREST PRODUCTIVITY TRENDS FOR TIMBER IN THE UNITED STATES[41]

Measures of Forest Productivity

Productivity, in economic terms, is defined as real output produced per unit of input employed in production. Productivity measures describe the quantitative relationship between inputs and outputs. They are different, therefore, from either measures of the quantity of production alone or measures of economic efficiency, which take into account the value of the inputs and outputs. Although measures of productivity for farm production have been in use for many years, similar measures for forestry have not been available. The forest productivity measures discussed here pertain to only one of the many important outputs from forests—timber. Forest productivity for timber is calculated as the ratio of the physical or real quantity of timber produced to the physical or real quantity of forest inputs employed in its production.

[41]*Most of the material in this section is taken from Ince and others (1989).*

Many inputs are employed in production of timber. The primary forest input of economic value is capital in the form of the timber growing stock resources of the forest. Timber growing stock volume (or "inventory") serves as a real measure of timber capital input employed in the production of timber. Another important forest input in production of timber is land. Timberland acreage serves as a real measure of forest land input employed in production of timber.

Real measures of timber output include timber growth and timber removals. Timber growth represents a purely biological measure of timber output. It is the amount of timber produced in the forest and stored on the stump for both present and future consumption. Timber removals are more of an economic measure of timber output and represent mainly the quantity of timber removed in commercial timber harvesting for present consumption. Whereas timber growth reflects the biological timber output of the forest, timber removals reflect wood market requirements and trends in harvesting and wood utilization technology.

Tables 126 and 127 contain data on timberland area, net annual growth, annual removals, and growing stock inventory in the United States, by ownership and section, for the years 1952, 1962, 1970, 1977, and 1987. These data are derived from the continuous forest surveys conducted by the USDA Forest Service. Growth, removals, and inventory are shown separately for softwoods (table 126) and hardwoods (table 127), since management and utilization of softwood and hardwood species have been very different over time. These tables also include three measures of forest productivity for timber, by ownership and section: (1) timber growth per acre, (2) the ratio of timber growth to inventory (growth/inventory), and (3) the ratio of timber removals to inventory (removals/inventory).

The ratios of growth to inventory and removals to inventory are displayed as indexes. The data value for growth, removals, or inventory for a given year is divided by the data value for 1977, and then multiplied times 100 to provide an index with 1977 = 100. 1977 was chosen as a base year for comparability with other USDA statistics and to provide a benchmark measure of change since the 1980 Assessment. The growth/inventory index is calculated by dividing the growth index by the inventory index. The removals/inventory index is calculated by dividing the removals index by the inventory index. The indexes highlight the magnitude and direction of change over time within each ownership class or each section. The indexes do not, however, allow direct comparisons of the absolute levels of inputs or outputs between ownership groups or sections. It should also be remembered that, although these productivity measures are developed in relation to a single input (timber capital or timberland), timber outputs are affected by a number of interrelated inputs, including the inputs of labor and forest management.

Table 126.—Timberland area, timber growth, removals, and inventory, growth per acre, and forest productivity indexes (1977 = 100) for softwoods in the United States, by ownership and section, specified years 1952–1987.

Year	Timberland area	Softwoods					
		Net annual growth	Annual removals	Total inventory	Annual growth per acre	Productivity indexes	
						Growth/ inventory	Removals/ inventory
	Million acres	*Billion cubic feet*			*Cu. ft.*		
United States, all owners and sections							
1952	509	7.7	7.8	430	15.2	67	83
1962	515	9.6	7.6	448	18.7	80	79
1970	504	11.3	9.3	458	22.5	92	94
1977	491	12.5	10.0	465	25.5	100	100
1987	483	12.9	11.4	451	26.6	106	117
Forest industry							
1952	59	1.9	2.8	77	31.7	61	74
1962	61	2.3	2.3	76	37.9	77	62
1970	68	2.6	3.1	75	38.9	88	85
1977	69	2.9	3.6	74	42.8	100	100
1987	71	3.2	4.2	72	45.5	112	119
Other private							
1952	297	3.5	3.5	94	11.7	78	131
1962	301	4.3	3.0	103	14.4	88	102
1970	286	5.2	3.3	114	18.3	96	102
1977	278	5.9	3.5	124	21.2	100	100
1987	276	5.5	4.2	135	19.8	85	109
National forests							
1952	95	1.7	1.0	204	17.6	69	53
1962	97	2.0	1.7	214	20.6	79	85
1970	95	2.4	2.2	212	25.0	94	106
1977	89	2.5	2.0	208	27.8	100	100
1987	85	2.8	2.1	186	33.0	127	116
Other public							
1952	58	0.7	0.4	55	12.6	66	52
1962	56	1.0	0.6	56	17.2	85	69
1970	56	1.1	0.8	57	20.0	96	89
1977	56	1.2	0.9	59	21.4	100	100
1987	51	1.4	0.9	57	27.0	120	105
South							
1952	205	3.6	3.1	59	17.8	97	117
1962	209	4.7	2.8	73	22.5	101	86
1970	203	5.6	3.7	87	27.8	102	95
1977	198	6.3	4.4	99	31.8	100	100
1987	195	5.8	5.7	104	29.9	88	123
West[1]							
1952	150	3.1	4.0	344	20.8	63	77
1962	150	3.7	4.3	341	24.7	75	82
1970	146	4.4	5.0	332	29.8	91	99
1977	139	4.6	4.9	322	33.2	100	100
1987	133	5.7	4.9	300	43.0	133	108
North							
1952	154	1.0	0.6	27	6.3	101	148
1962	157	1.2	0.5	34	7.7	101	101
1970	154	1.3	0.6	39	8.7	97	95
1977	153	1.6	0.7	44	10.2	100	100
1987	155	1.3	0.7	47	8.3	76	97

[1]*The West includes the Rocky Mountains and Pacific Coast.*
Source: Ince et al. 1989. Data have been revised slightly since publication of the earlier report.

Table 127.—Timberland area, timber growth, removals, and inventory, growth per acre, and forest productivity indexes (1977 = 100) for hardwoods in the United States, by ownership and section, specified years 1952–1987.

		Hardwoods					
						Productivity indexes	
Year	Timberland area	Net annual growth	Annual removals	Total inventory	Annual growth per acre	Growth/ inventory	Removals/ inventory
	Million acres	*Billion cubic feet*			*Cu. ft.*		
United States, all owners and sections							
1952	509	6.2	4.1	180	12.1	95	139
1962	515	7.1	4.3	211	13.8	93	127
1970	504	8.5	4.2	236	16.8	99	111
1977	491	9.4	4.2	260	19.2	100	100
1987	483	9.7	5.1	305	20.0	87	103
Forest industry							
1952	59	0.7	0.5	20	11.7	90	139
1962	61	0.8	0.7	25	13.5	87	142
1970	68	1.1	0.6	29	15.8	97	106
1977	69	1.2	0.6	32	17.7	100	100
1987	71	1.2	0.8	35	16.4	86	124
Other private							
1952	297	4.6	3.3	131	15.5	95	139
1962	301	5.1	3.4	149	17.0	93	127
1970	286	6.1	3.3	164	21.3	100	112
1977	278	6.7	3.2	181	24.1	100	100
1987	276	6.9	3.9	214	25.0	87	102
National forests							
1952	95	0.4	0.1	13	4.2	96	142
1962	97	0.5	0.1	17	5.2	96	121
1970	95	0.6	0.1	19	6.1	98	126
1977	89	0.7	0.1	21	7.4	100	100
1987	85	0.6	0.2	25	7.3	81	107
Other public							
1952	58	0.5	0.1	16	8.5	94	107
1962	56	0.6	0.2	21	11.4	96	89
1970	56	0.7	0.2	24	13.4	98	99
1977	56	0.8	0.2	26	15.1	100	100
1987	51	1.0	0.2	31	19.0	97	81
South							
1952	205	3.0	2.6	84	14.9	84	153
1962	209	3.4	2.7	95	16.3	83	150
1970	203	4.3	2.3	104	21.1	96	119
1977	198	5.0	2.2	116	25.2	100	100
1987	195	4.6	3.0	134	23.4	79	114
West[1]							
1952	150	0.4	0.0	19	2.6	80	44
1962	150	0.5	0.1	22	3.3	87	63
1970	146	0.6	0.1	25	4.1	94	93
1977	139	0.6	0.1	25	4.5	100	100
1987	133	0.9	0.1	31	6.4	108	76
North							
1952	154	2.7	1.5	77	17.8	112	126
1962	157	3.2	1.5	95	20.5	107	106
1970	154	3.6	1.7	107	23.3	106	106
1977	153	3.8	1.8	119	24.7	100	100
1987	155	4.2	2.0	140	27.3	95	94

[1]*The West includes the Rocky Mountians and Pacific Coast.*
Source: Ince and others 1989. Data have been revised slightly since publication of the earlier report.

Forest Productivity Trends, 1952–87

Timber growth per acre shows the trend in real biological timber output per unit of land area available for production of timber. This area, of course, includes many acres where production of timber is not the primary objective of the landowner. The growth/inventory index shows the trend in real biological timber output per quantity of timber capital employed in production of timber. The removals/inventory index shows the trend in timber output primarily for market per quantity of timber capital employed in production of timber.

These productivity measures reflect some of the major changes in the timber resource situation discussed in Chapter 3. The growth per acre trends for all owners (fig. 68) indicate that the biological productivity for timber of U.S. forests has increased substantially since 1952. Growth per acre has increased substantially and continuously for both softwood and hardwood timber. The growth/inventory index has increased substantially for softwood timber, but has declined recently for hardwood timber (fig. 69). It is evident that timberland is being used increasingly more efficiently for biological timber production, while timber capital is being used increasingly more efficiently for biological production of softwood timber but not for biological production of hardwood timber.

Forest productivity measures within ownership categories generally follow the same trends. An exception occurs in the other private ownership category, where softwood growth per acre and growth per unit of inventory have declined in the last decade (table 126). Most timberland in other private ownership is in the South and the North. Both these sections experienced significant gains in softwood growth and inventory from the 1950s until the late 1970s. Over the past decade, softwood inventories have continued to increase but net annual growth per acre has declined.

The net annual growth decline in the South has been the subject of much interest and study in recent years (USDA FS 1988b). Causes for the decline include inadequate regeneration of pine stands following harvest on other private lands, a significant increase in the volume of mortality and cull trees over the last decade, and a

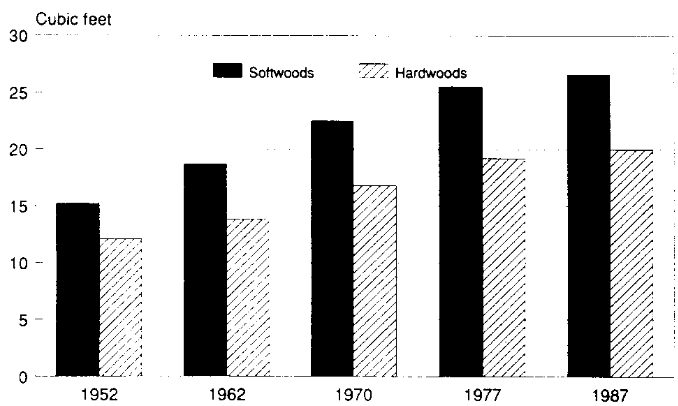


Figure 68.—Trends in net annual growth per acre in the United States, all ownerships.

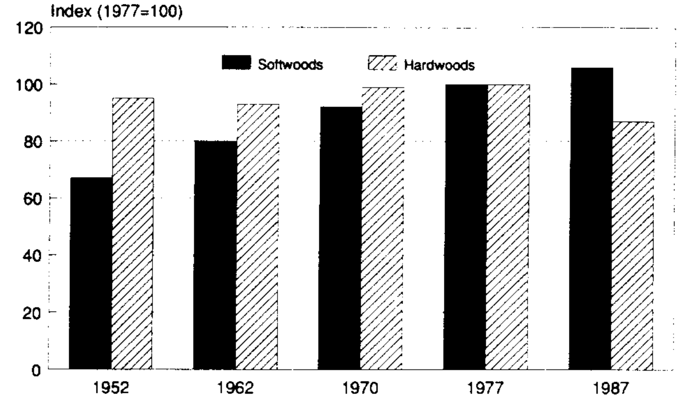


Figure 69.—Trends in growth/inventory productivity indexes in the United States, all ownerships.

decline in average annual radial growth of natural pine in some areas for reasons that are not yet understood. In the North, spruce budworm outbreaks have resulted in a dramatic drop in growth for balsam fir in Maine (Maine Department of Conservation 1988). In addition, much of the spruce-fir forest in this area was regenerated after severe budworm outbreaks in the early 1900s, and stands are reaching an age where growth is slowing down.

In contrast, softwood growth per unit of inventory has continued to make major gains in the West. In Pacific Coast areas especially, softwood inventories have been declining and net annual growth increasing as old-growth timber is harvested and replaced by vigorous young stands.

The decline in growth per unit of inventory for hardwoods reflects the continuing accumulation of hardwood growing stock on all ownerships as noted in Chapter 3. Net annual growth for hardwoods has been fairly stable in recent years or even declined in some areas as stands age and mortality increases.

The removals/inventory indexes for all owners (fig. 70) show that forest productivity for timber in the United States, as influenced by timber markets and utilization technology, has improved substantially for softwood timber. For hardwood timber, this measure of productivity has declined in previous decades and then, except for the other public ownership, increased in just the last decade, especially on forest industry ownerships (table 127). The indexes show that timber capital has been used increasingly more efficiently for commercial production of softwood timber while timber capital has been used less and less efficiently for commercial production of hardwood timber. The downward trend for hardwoods shows a small reversal in the last decade associated with increased utilization of hardwood timber.

Because timber removals are mainly commercial timber harvest volumes, the trend in forest productivity according to the removals/inventory index is influenced strongly by the market requirements for timber and the technology of wood use. The indexes reflect rising demands for softwood timber products over the past several decades which have generated large increases in softwood removals. In the late 1970s and early 1980s, technological advances in the manufacture of

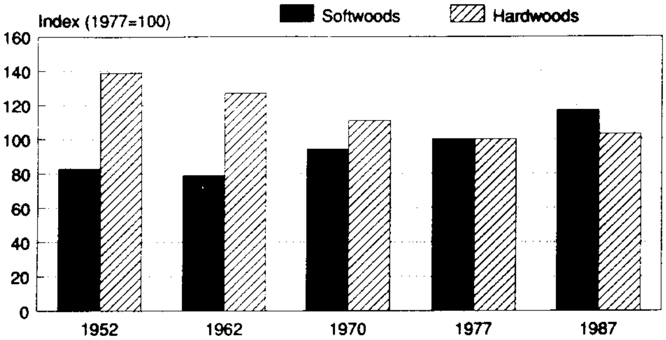


Figure 70.—Trends in removals/inventory productivity indexes in the United States, all ownerships.

pulp, paper, and board products and high demands for fuelwood stimulated greater utilization and harvest of hardwood timber.

Implications for the Future

The forest productivity measures presented here are by no means a complete measure of the productivity of U.S. forests. They do, however, highlight significant trends in timber production capabilities nationwide and across ownerships and geographical sections.

Over the past three decades, timber harvests from all ownerships have increased in response to rising demands for timber products. At the same time, total timberland area has gradually declined. Softwood net annual growth per acre of timberland and per unit of inventory, however, have also increased on all lands (with the exception of other private ownerships) in the last decade. The hardwood productivity indexes, on the other hand, reflect inventory accumulations that until recently have far outpaced harvests for market.

The projections in this Assessment indicate that demands for timber products will continue to rise in the future and that the timberland base will continue to decrease. Increasing timber growth would be one way to sustain higher levels of timber harvests in the next century. The increases in productivity on timberlands described earlier have come about in large part as a result of substantial public and private investments in forest research, management and protection, and education and technology transfer. Trends in these programs, especially over the last decade, are reviewed later in this chapter. The projections of timber supplies in Chapter 7 were based on the assumption that investments in timber management would continue at current levels or in some cases accelerate, especially on forest industry lands. Although substantial opportunities exist to increase timber growth on other private lands as well, the outlook for increases in productivity on these ownerships is more problematic.

RECENT TRENDS IN FOREST RESEARCH AND TIMBER MANAGEMENT

Forest Research

Research provides the knowledge and technology needed by forest managers to improve the productivity of their timberlands. Most forest management research is conducted by the USDA Forest Service and by forestry schools located at land grant colleges and universities, other state-supported and "1890" schools, and several private universities. Timber management and utilization research is also conducted by a few of the larger forest product companies. Some companies that do not maintain a staff of scientists or laboratory facilities still participate in research activities through university cooperatives and small staffs devoted to in-house problem-solving. Expenditures for forest management research, including primarily silviculture, genetics, economics, and mensuration, were approximately $30 million for the USDA Forest Service, $19 million for forest industry, and $17 million for universities in 1985 (Hodges et al., in press).

Major research efforts include development of cost effective and reliable silvicultural alternatives and timber management guidelines to improve forest growth, quality, and composition; genetic improvement for superior tree growth, quality, and resistance to forest pests; and mathematical models and computer programs to predict more accurately the growth and yield of forest stands. Research is also providing technology to prevent or reduce the impact of insects or disease on the timber supply; methods of preventing and controlling wildfire and prescribing fire to enhance production; assessments of the effects of atmospheric deposition on terrestrial and aquatic ecosystems; information and analyses of the timber resource; and technology to harvest and utilize timber more efficiently.

Most studies of economic returns on investments in forestry research have found high rates of return. Increases in the productivity potential of forest stands due to the development of new management technologies have been estimated at up to 70% for Douglas-fir and more than 200% for loblolly pine (Joint Council 1988). Genetic improvement in planting stock has been credited with increasing annual growth for some conifers by 20% to 40%, as well as improving other traits such as specific gravity, straightness, and disease resistance. Research has also advanced an understanding of the complex interrelationships at work within forest ecosystems, which is essential for multiple-use planning and management of timberlands.

Despite a continuing role for advances in knowledge and technology to meet the increasing demand for goods and services from forest lands, investments in forestry research generally declined between the late 1970s and early 1980s. Declines in funding paralleled reductions in the number of scientists engaged in forestry research and student enrollments in undergraduate and graduate forestry programs (Giese 1988).

Total appropriations for USDA Forest Service research fell by almost 25% in constant dollars between fiscal years 1977 and 1986. In the following fiscal years, this downward trend turned around somewhat as funding levels increased. In fiscal year 1989, appropriations for Forest Service research in all areas totaled $137.9 million.

Funding for university-based research comes primarily from state and private sources with significant support from McIntire-Stennis and other federal funds. Nonfederal funding for forestry research has increased by nearly 30% in the past decade, compensating in part for a decline in federal contributions. Expenditures from all sources for forestry research at universities was approximately $88 million in fiscal year 1986 (Joint Council 1988).

Information on expenditures by forest industries is not readily available, and much of the research accomplished is proprietary in nature. The American Forest Council estimates that research investments by forest industry have declined by more than 30% since 1982 (Joint Council 1988).

Sustaining the significant gains in forest productivity for timber achieved over the last several decades would require continuing development and implementation of new knowledge on the biological and economic factors affecting timber growth and harvest balances. Opportunities exist, for example, to improve productivity on timberlands over the long run through basic research on the fundamental physiological and biological processes of tree growth, through development of new and improved timber management techniques, and through accelerated implementation of technologies as they are developed. Realizing the potential gains in productivity made possible by research requires on-the-ground actions by public and private forest land managers. Recent trends in putting available timber management technology into practice are discussed in the next section.

Timber Management

Timber management encompasses a wide variety of land and stand management activities that are designed to increase timber growth and protect against losses. Such activities include stand regeneration after timber harvesting or on nonstocked land, conversion of acres with offsite species to a preferred forest type, improved scheduling of harvest for mature timber, intermediate stand treatments to improve tree growth or quality, and management of fire, insects and disease to reduce losses. Investments in timber management result in substantial increases in timber growth over time on the growing stock and land base available for timber supplies.

Regeneration Trends

Most forest regeneration occurs naturally or through harvest practices designed to encourage natural regeneration. Natural regeneration of softwoods following logging may require 3 to 5 years in the South and 5 to 10 years in the West. Lack of adequate regeneration to desired species may result in changes in forest type. Over large areas of the South, for instance, a natural succession to hardwoods occurs after harvest of pine stands unless action is taken to encourage regeneration of pine. In contrast to softwoods, hardwoods usually regenerate rapidly and easily, mostly from stump and seedling sprouts. To alter the species mix on a site to favor preferred species, however, special silvicultural systems and site preparation treatments may be necessary (Burns 1983).

Artificial regeneration—planting and direct seeding—requires an initial investment, but generally gives faster and more certain results than natural regeneration. It provides better control of species, spacing, and stocking levels and allows the use of genetically improved stock. Most regeneration through planting and seeding is with commercially important softwood species, chiefly southern pines and Douglas-fir.

Planting of seedlings raised in nurseries accounts for nearly all artificial regeneration. Both industry and government are increasing their efforts to plant superior trees by improving the quality of such seedlings. Currently 68% of state-produced tree seedlings (Risbrudt and McDonald 1986) and 99% of federal nursery stock (USDA FS 1987a) are of genetically improved quality. Forest industry has also made major advances in the use of genetically improved seedlings.

Nationwide data on acres regenerated naturally are not available. Since 1982, however, new records for acreage regenerated by planting and direct seeding have been set each year. In 1988, nearly 3.4 million acres were artificially regenerated nationwide (USDA FS 1988c). Four-fifths of the acres regenerated were in the South (fig. 71). Virtually all artificial regeneration is accomplished through tree planting rather than direct seeding. Direct seeding was used on 40,000 acres in 1988, only 1% of the total acres artificially regenerated.

Nationwide in 1988, other private ownerships accounted for 47% of artificial regeneration accomplishments; forest industry ownerships accounted for 40%. Less than 15% of the acres planted or direct-seeded were on public ownerships—9% on national forest lands and 4% on other public lands.

Peak years of tree planting prior to 1982-88 occurred during the era of the Soil Bank Program from the mid-1950s to the early 1960s (fig. 72). The Soil Bank Program made payments to farmers to retire land from crop

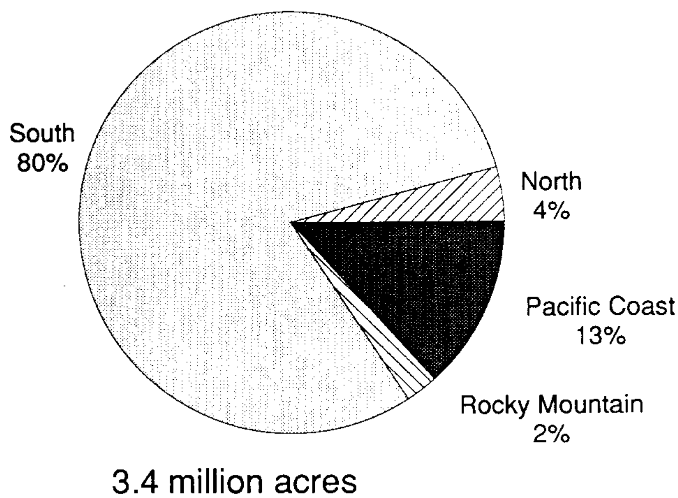


Figure 71.—Area planted and direct-seeded in the United States, by section, 1988.

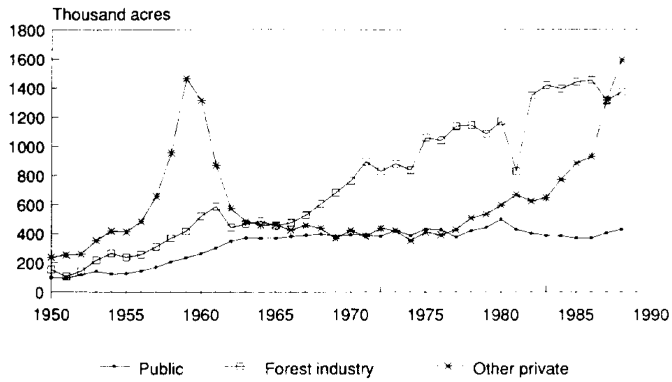


Figure 72.—Area planted and direct-seeded in the United States, by ownership, 1950–1988.

production, with most planted tracts remaining in trees after the program expired (Alig et al. 1980). Planting and direct seeding on farmer and other private ownerships accounted for nearly 70% of the artificial regeneration activity in 1959.

Following the end of the Soil Bank Program, artificial regeneration on forest industry lands surpassed planting and direct seeding on other private lands. During the 1960s and 1970s, most of the increase in artificial regeneration occurred on forest industry ownerships in the South and the Pacific Coast. During the 1980s, forest industry planting and direct seeding have averaged about 1.3 million acres per year, about half the total.

In 1987, for the first time in 20 years, artificial regeneration reported on other private ownerships surpassed tree planting and direct seeding on forest industry lands. This increase in artificial regeneration on other private ownerships has coincided with the implementation of a number of policies and programs designed to stimulate investments in forestry. These policies and programs include restructured educational and technical assistance programs under the Renewable Resources Extension and Cooperative Forest Management Acts, the reforestation tax credit and amortization provisions enacted in 1980, direct financial assistance for reforestation under the federal Forestry Incentives Program, a variety of state cost-share programs, and most recently the Conservation Reserve Program. These programs are discussed in more detail in a later section.

In recent years, tree planting in the South has exceeded 2 million acres per year. Other private owners planted nearly 1.5 million acres in 1988, and forest industry planted over 1 million. Artificial regeneration in the Pacific Coast section has involved around 400,000 acres per year, primarily on public and forest industry lands. Although planting activity in 1988 surged to 454,000 acres, this amount is still down somewhat from peak years in the late 1970s, when planting occurred on a half million acres per year, over 20% of the national total. Tree planting in the North has also declined from a peak of over 300,000 acres per year during the Soil Bank era to an average of 150,000 acres per year over the last 5 years. Other private and public ownerships reported the most activity. Tree planting in the Rocky Mountain section has always represented a minor portion of the national total. In recent years, artificial regeneration has run about 100,000 acres per year, a modest increase since the 1970s. Three-fifths of the acres regenerated in 1988 in this section were public lands.

Intermediate Stand Treatments

Management practices during the period between regeneration and harvest cuts can increase timber supplies by changing the composition of stands in favor of desired species, reducing the number of defective trees, increasing growth on favored residual trees, and releasing desirable seedlings on recently regenerated areas. In addition, fertilizing stands and draining areas where excess moisture slows growth can increase growth rates. In recent years, intermediate treatments have been reported on about one and a half million acres per year, with over half on forest industry lands, primarily in the South, and another quarter on national forest lands, especially in the West (USDA FS 1988c).

The most widespread intermediate treatment is thinning stands to remove low-value timber, to speed growth of desirable species and trees, and to shorten timber rotations by concentrating growth on residual trees. Pruning the lower branches on young trees that are expected to be part of the final crop can also increase the quality and value of timber growth. Although pruning has little effect on total timber supplies, it can increase supplies of high-quality timber. Overall, pruning has not been widely used in the past.

Fertilization of forests can increase timber supplies where experience and research show that lack of soil nutrients is limiting plant growth. The biggest opportunities seem to be on the nitrogen-deficient soils of the Douglas-fir region and the poorly drained phosphorus and nitrogen-deficient soils of the Coastal Plains of the South. In the Douglas-fir region, addition of nitrogen fertilizer typically results in a range of response from 200 to 800 gross cubic feet over a 10-year period, with the higher levels of response coming from low-quality sites. The use of phosphorus fertilizers in newly planted pine forests on poorly drained sites on the southern Coastal Plain is generally expected to increase yields in 25-year-old stands by around 15 cords. The use of nitrogen fertilizer in these stands when they are from 10 to 25 years old also increases harvest yields substantially.

Although the use of fertilizers on commercial timberlands outside the Coastal Plain of the South and the Douglas-fir region has so far been limited, there may be opportunities in other regions. There are also some specialized uses. For example, research has shown that with fertilization black cherry seedlings and sprouts can, in one season, outgrow the reach of browsing deer.

Reduction of Losses

The growth of timber can be reduced by poor harvesting practices, wildfire, insects, and diseases. Management practices that reduce losses from these causes and result in rapid salvage of dead and dying timber can add substantially to net annual growth and the volume of timber available for use. Harvesting activities often damage residual trees and may increase the risk of insect attacks, windthrow, and fire on adjacent timber stands. Improvements in logging practices to minimize damage and the protection of residual trees against destructive agents such as wind, insects, and disease could significantly reduce the mortality and growth loss associated with harvesting.

Fire management trends.—The most effective timber management effort in the United States has been the control of forest fires. Although recent years have brought several exceptionally severe fire seasons, the long-term results of fire management programs have been remarkable. The area burned annually declined from 30 to 40 million acres at the beginning of the century to 3 to 5 million acres between 1980 and 1986. Almost all timberland and large tracts of nonforested watershed are now protected by federal, state, and private organizations. Federal expenditures for fire protection on national forest lands averaged about $250 million annually in the 1980s. Federal and state expenditures to protect state and private lands have historically exceeded the levels expended for national forests. The improvement in protection has contributed in a major way to the increases in net annual growth and timber inventories which have been taking place in eastern forests in recent decades.

The rate of reduction in the area burned annually, however, has slowed significantly in recent years. Increasing fire management efforts have been offset by greater risks associated with improved access to and increased use of forest lands as well as the natural accumulations of fuels on unburned protected areas. Accumulation resulting from management practices such as harvesting and thinning, along with air quality constraints on burning such material, contribute to the problem.

Another factor is the expansion in areas where wildlands intermingle with residential development. In wildland and urban interface areas, the encroachment of structures in and about the forests has increased fire hazards. Fire suppression forces must protect human life and residential property in the interface areas—often at the expense of allowing increased acreage of forest land to burn. Accelerated research to improve technology of fire prevention, presuppression and suppression, and other measures such as closer timber utilization could reduce fire risks on timberlands.

Insect and disease management trends.—Insects and diseases take a heavy toll of timber by killing trees and by reducing timber growth and quality. A few major pests such as the western bark beetle, southern pine beetle, and root rot account for much of the mortality. Other insects and diseases such as spruce budworms, dwarf mistletoes, and gypsy moths also cause tree mortality, but they cause considerably more damage in the less spectacular form of killing branches, shoots and terminals; reducing the rate of growth; and stunting, deforming, or degrading the value of trees and wood products.

Forest pests can cause widespread outbreaks resulting in extensive tree mortality, deformity, growth reduction, decay, and reproduction failure. The actual consequences of these effects, however, depend largely on specific management objectives and forest resource values. As a result, forest pest management considerations are closely linked to forest management objectives and operations that define the need and provide the means for preventing or reducing pest-caused losses.

Annual federal and state expenditures for forest insect and disease protection were $38.2 million in 1987. This amount represents a moderate decline (in constant dollars) over the past decade. Throughout the 1980s, about 40% of the total expenditure has gone to the North, 25% to the South, and 35% to the West. About 80% of North and South expenditures was used to suppress pests on private and other public lands. The expenditures in the West were largely to suppress pests on federal lands.

During the late 1970s and early 1980s, private and other public expenditures averaged about 70% of total expenditures. From 1983 to 1988, private and other public expenditures averaged about 55%. This change began when federal expenditures increased in response to southern pine beetle, mountain pine beetle, and western spruce budworm outbreaks on federal land. The change also coincided with the end of federally supported spruce budworm suppression in Maine and a collapse of gypsy moth populations in parts of the North.

In the Pacific Coast and Rocky Mountain regions, most losses from insects and diseases have been caused by western spruce budworm, mountain pine beetle, dwarf mistletoe, and root disease. Since 1982, approximately $14.0 million has been spent for western spruce budworm suppression, $15.3 million for mountain pine beetle suppression, and $5.8 million for dwarf mistletoe suppression. Root diseases are a particular concern because they not only cause outright tree mortality, butt rot, and growth loss, but they also predispose trees to insect attack and windthrow. By affecting the growing site, root diseases remove large areas of productive forest land from full timber production. Management strategies which limit stand disturbance and exploit differences in tree species susceptibility can be used to reduce losses from root disease.

In the South, a large portion of the expenditure—$17.9 million since 1982—has been for the suppression of the southern pine beetle, the most damaging insect pest in that region. Fusiform rust, a botanical curiosity before 1900, is a disease that now flourishes across the South killing or deforming millions of slash and loblolly pines each year. Increased use of genetically resistant planting stock coupled with wider application of improved management strategies may help slow the increasing trend of this disease.

In the North, recent suppression efforts have been mainly concentrated on the gypsy moth in Maryland, New Jersey, Pennsylvania, Rhode Island, and West Virginia. Since 1982, approximately $38.4 million has been expended for gypsy moth suppression. In 1982, $8.6 million was spent on spruce budworm suppression in Maine.

Improvements in pest management technology such as stand risk rating, pest outbreak and damage prediction models, biological pesticides and pesticide application techniques, geographic information systems, and pest-complex prevention and control strategies have expanded the opportunities for increasing timber supplies by reducing pest-caused losses. Rapid salvaging of dead or damaged timber following wildfires, insect and disease outbreaks, and wind storms can also reduce losses of timber. Since a large part of the losses to destructive agents are comprised of individual or small groups of trees, the development of more cost effective harvesting systems could facilitate salvage operations.

More complete integration of forest pest considerations in the forest planning process and in resource management operations will be needed, however, to better realize recent technological gains. Such integration would permit more timely application of effective prevention and suppression strategies for forests where economic and other values permit treatment.

ECONOMIC OPPORTUNITIES FOR ACHIEVING INCREASES IN PRODUCTIVITY ON TIMBERLANDS

Significant gains in productivity of U.S. timberlands have been achieved over the past three decades. Still, many opportunities to enhance productivity on existing timberlands remain. Nationwide, many acres could be managed to grow higher wood volumes per acre, more preferred species, and/or higher valued products. These opportunities to increase timber growth exist on stands that are poorly stocked, have competing vegetation, have offsite species, are financially overmature, or are in some other less productive condition. Although implementing these opportunities would require substantial investments, many of these investments would yield a return of 4% or more in constant dollars (net of inflation or deflation). The 4% rate approximates the average long-run opportunity cost of capital in the private sector (Row et al. 1981).

Opportunities to increase productivity exist on all ownerships, but the greatest potential is on private ownerships. Decisions on future management of private timberlands tend to be less constrained by institutional factors and freer to respond to economic opportunities than management choices for public lands. Currently, over 84 million acres of private timberland are suitable for investments in regeneration or stocking control to increase timber growth or produce higher valued timber products (fig. 73). Seventy-nine percent of these potential timber investment opportunities occur on private ownerships other than forest industry. These other private ownerships control the largest area of timberland, 57% of all timberland in the United States, and their lands are less likely to be intensively managed at present than forest industry lands.

On forest industry lands, stand management to enhance productivity is essential to maintain competitive wood supplies for mills. Scheduling of stand treatments

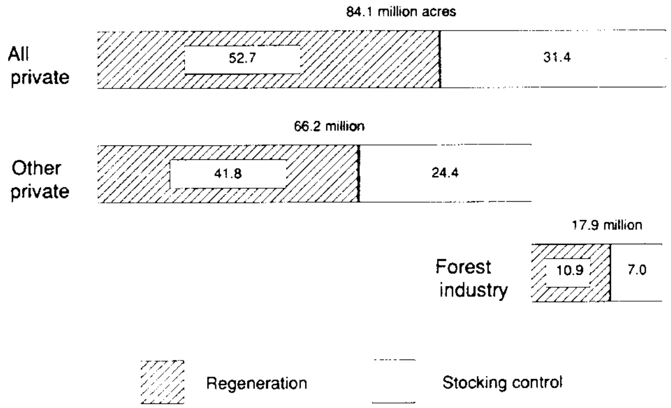


Figure 73.—Acres of private timberland with economic opportunities to increase timber growth, by ownership and type of treatment, with 4% return.

is likely to depend on annual cash flow and profitability considerations; and, even on industry lands, sites with low productivity or high treatment costs, small tracts, sites with environmental limitations, or areas with development potential for nontimberland use may remain untreated. By and large, however, forest industry lands are highly productive sites and are actively managed to increase their productivity. Therefore, most of the economic opportunities currently existing on forest industry lands are likely to be implemented.

On public lands, treatment opportunities are often constrained by site characteristics and multiple-use management objectives. As discussed in Chapter 3, the origins of the national forests resulted in large areas of relatively inaccessible and unproductive timberland being incorporated in the national forest system. Furthermore, on national forest lands the implementation of timberland investment opportunities is determined by forest plans. Although timber production is emphasized for some areas, emphasis for others is on nontimber outputs which may require longer rotations, more diverse stands, and less intensive management than would be appropriate for maximizing wood production. Decisions on whether or not to implement opportunities to increase timber growth or financial returns from timber production are subject to public policy determinations as well as economic analysis and must then be incorporated in forest plans.

A similar process applies to forest management decisions on many other public lands. Some of these lands are highly productive, such as the revested Oregon and California railroad grants lands in western Oregon administered by the Bureau of Land Management. Others, such as many of the county lands in Minnesota that were obtained as tax delinquent lands in the 1930s, have low productivity. Many of these public ownerships are managed for multiple purposes with important constraints on timber management and harvest. In some cases, however, such as state lands in Washington, public managers are expected to maximize income from their timberlands. Opportunities to increase returns from timber production then become an important consideration in the planning process.

The following analysis of economic opportunities to increase the productivity of timberlands concentrates on nonindustrial private ownerships because these ownerships have the largest share of opportunities for investment. It is recognized that nontimber outputs are often an important management objective for nonindustrial private landowners. Many of these other private lands, however, have not been managed to achieve their potential for timber or nontimber benefits. The joint production of timber and other outputs may require somewhat lower management intensity than reflected by the treatments described in this chapter. Still, on many sites, goals for increased wildlife and recreation outputs can be achieved more effectively by management of stand stocking, harvesting, and regeneration in a manner that will simultaneously improve timber outputs.

Acres on other private ownerships that are suitable for more intensive timber management, the expected return from the recommended treatments, and the additional timber volumes that could be produced are described below. These economic opportunities were identified using analytical techniques and information on stand responses to management developed for previous assessments of timber resources (USDA FS 1982, 1988b). Data on the timberland area suitable for treatment were the most recently available for each state.

Methods and Assumptions

Timberland Area Suitable for Treatment

The primary statistical base for identifying opportunities to increase timber supplies consisted of data on areas of timberland suitable for treatment compiled for each state by USDA Forest Service, Forest Inventory and Analysis units. Timber stand conditions on each sample plot were evaluated to determine treatments that could increase productivity. In many cases, stands were judged to be sufficiently productive so that no specific treatment was warranted at the time.

Forest treatments were separated into broad treatment classes for the purpose of analyzing economic opportunities. Regeneration treatments were prescribed where stand conditions indicated that a newly regenerated stand would be significantly more productive than the existing stand. Stocking control treatments were aimed at correcting timber stocking conditions that were impairing growth and development of commercial stands.

Regeneration treatments include:

- **Regeneration with or without needed site preparation.**—These acres lack manageable timber stands because of inadequate growing stock. Examples include poorly stocked land, recently harvested stands, failed plantations, and similar stands with insufficient stocking. Treatment of these stands involves immediate natural regeneration or planting. Site preparation may be required to assure adequate stocking and limit competing vegetation on some sites.
- **Conversion to a preferred management type for acres with offsite species.**—These are stands with chronic disease or pest problems, undesirable or offsite species, high proportions of cull trees, or high stress with trees of poor vigor. Conversion involves planting to a different management type or natural regeneration to favor a more desirable species distribution.
- **Harvest of financially mature timber followed by regeneration.**—These are financially mature or overmature sawtimber stands with sufficient volume to justify a commercial harvest. Most stands contain valuable sawtimber and could be held, but the volume and value growth rate of a replacement stand would be higher. These stands need to be harvested and regenerated naturally or planted.
- **Partial harvest of merchantable timber with natural regeneration.**—These are typically poletimber and sawtimber stands with enough merchantable volume for a commercial thinning or regeneration harvest. Stands have a favorable species composition and may be even- or uneven-aged. Treatments such as commercial thinning, seedtree or shelterwood regeneration cuts and selection harvest are appropriate.
- **Salvage of damaged timber followed by regeneration.**—These stands are excessively damaged due to fire, insects, disease, wind, ice, or other causes. These stands have unproductive areas where timber has been killed, trees have broken tops, or trees are threatened with additional damage from insects or diseases unless harvested. Average growth and yields of higher valued products are significantly reduced in these stands and harvest or removal of damaged or threatened timber is recommended, followed by regeneration.

Stocking control treatments include:

- **Control stocking of undesirable trees.**—These stands have adequate growing stock mixed with competing vegetation limiting crop tree development. Deadening or removal of stems that will not yield an adequate return is needed to release overtopped trees, to prevent stagnation and/or improve composition, form, or growth of the residual stand.
- **Precommercial thinning of overstocked seedling and sapling stands.**—These densely stocked stands include plantations with many volunteer stems, overstocked natural stands, hardwood thickets, and similar young stands with too many trees per acre. These stands are likely to stagnate and need precommercial thinning to help crop trees attain dominance.
- **Commercial thinning of dense poletimber stands.**—These poletimber stands are overstocked and need thinning to reduce stocking, prevent stagnation, and confine growth to fewer high-quality crop trees.

Acres were also classified by site class and forest management type for economic analysis. Three site classes based on potential productivity of well-stocked timber stands were used: high sites are capable of growing more than 85 cubic feet per acre per year; medium sites are capable of growing from 50 to 84 cubic feet annually; and low sites can grow from 20 to 49 cubic feet per acre per year.

Broad forest management types appropriate for each region were used for analysis. The forest management types in the southern states include planted pine, natural pine, mixed pine-hardwoods, upland hardwoods, and bottomland hardwoods. The forest management types in northern states are red, white, and jack pine; loblolly-shortleaf pine, spruce-fir, swamp conifers, oak-pine, aspen-birch, lowland hardwoods, maple-beech-birch, and oak-hickory. The forest management types in western states are coastal Douglas-fir, inland Douglas-fir, hemlock, fir-spruce, ponderosa pine, lodgepole pine, mixed conifers, larch, redwood, red alder, and aspen.

Management Options

Although many management options are possible for each stand condition, one preferred option was selected for each class of acres. In general, selected options favored more intensive regeneration treatments, stocking control, and treatments to produce shorter rotations and higher valued or larger crop trees. Natural stand management was preferred in cases where artificial regeneration was considered inappropriate or uneconomic.

Separate options were developed for managed and unmanaged stands to compare incremental gains resulting from treatments. The treated option was used to project results if specific management practices were applied to increase productivity. Treated stands were assumed to be kept highly productive with continued treatments for the analyses. The untreated option was used to determine foregone timber harvests for untreated stands. Minimal custodial management was assumed to continue for these cases indefinitely. All management options were carried out for a minimum of 150 years to assure a consistent investment period for comparison of treated and untreated stands.

Timber Yields

Harvest timber volumes were based on empirical yield tables for fully stocked stands. Yield tables included growing stock volume, percent softwood stocking, and percent of growing stock volume in sawtimber for each forest type and site class. Yields reflected average stocking and growth conditions for all stands in each group rather than site specific yields.

Economic Assumptions and Analysis

Management options were combined with treatment costs, yields, and stumpage prices to project cash flows for each investment opportunity (USDA FS 1987a). Stumpage prices used for the analyses were projected to rise over the investment period, in keeping with the trend for rising prices in the base case projection discussed in Chapter 7. Constant dollars were used for all stumpage prices and costs so that the effects of inflation or deflation were excluded. Only direct costs for treatments, such as stand establishment or stocking control, and costs associated with harvesting or selling timber were included. Costs that would accrue regardless of the treatment, such as ad valorem taxes, were excluded from financial analyses. Land costs and income taxes were also excluded.

For treated stands, opportunity costs due to foregone revenues from untreated stands were included. These opportunity costs were based on revenues that would have been earned if stands were not treated. Similarly, expected future costs for untreated stands were included as avoided costs for treated stands. Because of the large number of possibilities, it was not possible here to examine the dynamics of how opportunities for investment might change over time if scheduled treatments are actually postponed or otherwise adjusted.

A 4% real rate of return was used for discounting all costs and revenues. Although 4% approximates the average long-run rate of return on investments in the private sector, it is an average, and many management options yield higher rates of return. Some investments in stand treatments can earn rates of return in the range of 10% or higher.

Economic Opportunities by Region

There are economic opportunities to increase timber growth and/or financial returns from growing timber on over 66 million acres of other private timberland nationwide (table 128). This area represents about one-quarter of the timberland in other private ownership in the states included in the analysis. About two-thirds of these opportunities involve some form of regeneration activity (fig. 73). About one-third of the opportunities require stocking control measures in existing stands.

Approximately three-quarters of the opportunities are in the two southern regions, the Southeast and South Central. Nearly one-fifth of the opportunities are in the two northern regions, the North Central and Northeast. The small percentage of opportunities in the western states reflects in part the relatively small proportion of timberland held by other private owners in the West.

Within sections, the South also has the largest percentage (36%) of timberland in other private ownership with opportunities for management that would yield 4% or more return on the investment (table 128, fig. 74). Approximately 30% of the timberland in the Pacific Coast section and only 12% of the timberland in the North hold similar opportunities. Opportunities in the Rocky Mountain section are very limited, not only because of the relatively small area of timberland in other private ownership, but also because of the generally lower productivity of these lands compared to areas in the Pacific Coast.

Table 128.—Economic opportunities yielding 4% or more[1] for increasing forest productivity for timber on other private ownerships[2] in the contiguous United States, by region and treatment opportunity, in 1987.

Region and treatment opportunity	Area of timberland	Area with treatment opportunities	Cost of treatment	Net annual growth increment
	Million acres	*Million acres*	*Million dollars*	*Million cubic feet*
Northeast				
Regeneration[3]		([4])	0.8	0.5
Stocking control[5]		6.7	233.2	181.6
Total	57.7	6.7	234.0	182.1
North Central				
Regeneration		4.4	584.2	340.5
Stocking control		1.8	57.7	78.8
Total	49.0	6.2	641.8	419.4
Southeast				
Regeneration		18.1	1,965.5	835.4
Stocking control		6.7	318.6	268.7
Total	59.0	24.8	2,284.1	1,104.1
South Central				
Regeneration		16.8	2,442.9	865.0
Stocking control		7.9	372.5	333.7
Total	78.4	24.7	2,815.3	1,198.7
Rocky Mountain[6]				
Regeneration		0.1	21.0	4.5
Stocking control		0.1	3.3	2.8
Total	4.9	0.2	24.3	7.3
Pacific Northwest				
Regeneration		1.3	423.0	329.4
Stocking control		0.8	33.9	34.2
Total	6.9	2.1	456.9	363.6
Pacific Southwest				
Regeneration		1.1	178.0	160.4
Stocking control		0.3	6.9	11.0
Total	4.7	1.4	184.9	171.4
Contiguous States				
Regeneration		41.8	5,615.3	2,535.8
Stocking control		24.4	1,026.1	910.7
Total	260.6	66.2	6,641.4	3,446.5

[1] *Includes those opportunities which would yield 4% or more in constant dollars (net of inflation or deflation) on the investment.*
[2] *Private ownerships other than forest industry.*
[3] *Regeneration includes opportunities to reforest inadequately stocked stands, to convert off-site species to more productive forest management types, and to harvest mature timber and regenerate.*
[4] *Less than 50,000 acres.*
[5] *Stocking control includes commercial and noncommercial thinning, cleaning, and release.*
[6] *Includes only the economic opportunities in Idaho and Montana. Other states in the Rocky Mountain and Great Plains regions are excluded.*
Note: Data may not add to totals because of rounding.

Implementation of the opportunities on other private lands would increase net annual growth by close to 3.5 billion cubic feet, primarily from investments in regeneration of nonstocked and understocked sites, conversion of areas to preferred species, and harvest of mature timber followed by regeneration. Almost all of this increase would be softwood growth. Current net annual growth of softwoods would increase by about 55% (fig. 75). There are also economic opportunities to increase hardwood growth by 470 million cubic feet, a 7% increase over current net annual growth.

Investments of over $6.6 billion dollars would be needed to implement all of these opportunities. Over 75% of these funds would be needed in the South Central and Southeast regions (table 128).

Nearly 30% of the economic opportunities nationwide would yield rates of return of 10% or higher. Implementation of these opportunities would increase total net annual growth on other private ownerships by over one billion cubic feet. The investments required for these treatments would be around $1.6 billion. Most of these

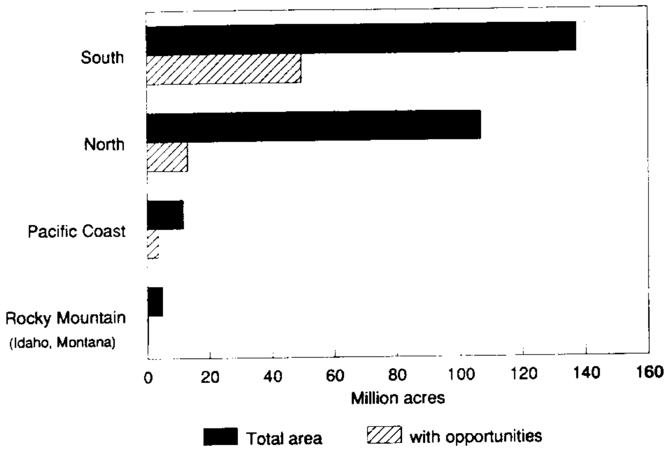


Figure 74.—Area of timberland in other private ownership, total area and area with economic opportunities, by section.

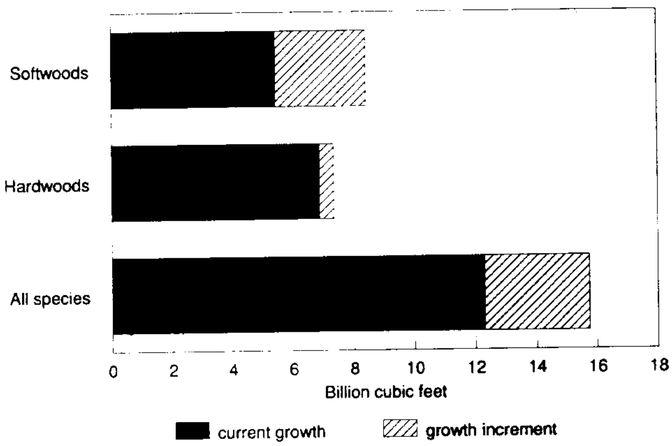


Figure 75.—Current economic opportunities to increase net annual growth on other private timberland, for softwoods and hardwoods, with 4% return.

opportunities are also in the two southern regions and involve some form of reforestation.

North

Close to 70% of the timberland in the North is in other private ownership. The analysis of economic opportunities in the North included treatments for softwood stands, especially red pine, white pine, and spruce/fir, and for hardwood stands, primarily oak-hickory and maple-beech-birch forest types. The forest resource and the associated opportunities are quite distinct between the Northeast and the North Central regions.

Northeast.—There are economic opportunities to increase timber growth on approximately 6.7 million acres of timberland in other private ownership in the Northeast. Unlike other regions, the bulk of these opportunities consists of stocking control treatments for hardwoods. Economic opportunities to reforest or convert to preferred species are limited in the Northeast. Stocking control treatments on 5 million acres of oak-hickory and maple-beech-birch stands would increase net annual growth for hardwoods by over 112 million cubic feet. Another 70 million cubic feet of softwood growth could be obtained by intermediate stand treatments on 1.5 million acres of red and white pine and spruce/fir.

Implementation of all opportunities would increase current net annual growth in the Northeast by about 8%. The cost for all treatments would be approximately $234 million. Economic returns from these investments generally range between 4% and 9%. None of the treatment options analyzed had an average rate of return of 10% or higher.

North Central.—In the North Central region, approximately 6 million acres have economic opportunities to increase timber growth, or about 13% of the timberland in other private ownership. About 70% of these opportunities involve regeneration treatments. Net annual softwood growth could more than double with an addition of 300 million cubic feet of growth. Hardwood growth could be increased by 8% with 116 million cubic feet of additional growth per year. Investments of $642 million would be needed to implement all of the opportunities.

Most of the opportunities are found in the Lake States (Michigan, Minnesota, and Wisconsin). Large opportunities exist to increase softwood growth by converting jack pine and hardwood stands on low sites to red pine. Commercial thinning of red pine plantations also offers favorable returns. Hardwood growth could be increased by clearcutting and regenerating aspen-birch stands on high sites. The largest opportunities for increasing hardwood growth, however, consist of commercial thinning of oak-hickory and maple-beech-birch stands on better sites. Opportunities in the central part of the region are limited primarily to stocking control treatments of oak-hickory and maple-beech-birch stands.

As in the Northeast, none of the treatment opportunities analyzed had an average rate of return of 10% or higher. Most of the treatments had an average rate of return of 5% to 7%.

South

Approximately 70% of the timberland in the South is in other private ownership. For the evaluation of economic opportunities in the Southeast and South Central regions, the selected management option in most, but not all, cases was to establish pine plantations. Bottomland hardwood stands were not converted to pine except in cases where stand conversion was recommended as the needed treatment by forest inventory data. Natural regeneration was evaluated for bottomland hardwood stands on high-quality sites. Natural pine, mixed pine-hardwood, and upland hardwood forest management types on low-quality sites were assumed to be managed by natural regeneration methods in most instances. Only in cases where site preparation was required for regeneration, salvage, or type conversion of low sites for these types did management options include artificial regeneration to pine plantations.

In addition to the opportunities on timberland discussed below, the South is in a unique position compared to other sections in the opportunities that exist to augment timber growth through tree planting on marginal cropland and pasture. Because of the minimum site preparation costs involved, tree planting on unused cropland and pasture offers a relatively high rate of return. A recent study estimated that nearly 22 million acres of marginal cropland and pasture in the South would yield greater returns as pine plantations than in crop or pasture use (USDA FS 1988b). If planted to pine, these acres could add about 2.1 billion cubic feet of timber growth per year. A similar analysis in the North and West, comparing potential returns from tree-planting and crops on idle cropland, estimated that investments in forestry would be more profitable than crops on less than 2 million acres (Parks et al. 1988). The more profitable investments were limited to planting high-valued species in specific areas, such as black walnut in parts of the Allegheny Plateau and Catskill Mountains and redwood in the California Coastal Redwood Belt.

Southeast.—There are economic opportunities for increasing forest productivity for timber on about 25 million acres of other private timberlands in the Southeast, over two-fifths of the timberland area in this ownership category. Treatment of this area would increase net annual growth by 1.1 billion cubic feet, primarily for softwoods. This additional growth represents a 58% increase over current net annual growth for softwoods on other private lands and a 31% increase for all species. Achieving this additional growth would require an investment of $2.3 billion.

On an area basis, almost three-quarters of the economic opportunities consist of some form of reforestation or stand conversion. Opportunities exist, for example, to clear, site prepare, and plant pine on 2.2 million acres of nonstocked timberland and over 7 million acres of timberland occupied by poorly stocked oak-hickory, oak-pine, or natural pine stands. Net annual growth could be increased on another 4 million acres if mature stands and stands severely damaged by insects, disease, or other elements were harvested and regenerated to pine. Opportunities also exist to increase net annual growth through regeneration on nearly 3 million acres of bottomland hardwood lands. Most of this increase would come from natural regeneration of bottomland hardwoods on high-quality sites that are poorly stocked or occupied by mature or overmature stands. If all of the opportunities for reforestation and stand conversion on other private ownerships were implemented, net annual growth in the Southeast would increase by over 835 million cubic feet. Most of this growth would be from softwoods.

Opportunities to increase net annual growth by intermediate stand treatments such as stocking control exist on close to 7 million acres in other private ownerships in the Southeast. Net annual growth would increase by 270 million cubic feet, primarily from treatments such as removing competition from hardwood trees in pine stands and competition from trees of less desirable species or form in hardwood stands. This increase in growth also includes gains from precommercial thinning of seedlings and saplings and commercial thinning of poletimber. Most of these opportunities are found in natural pine and mixed pine-hardwood stands.

Nearly half of all the economic opportunities to increase forest productivity on other private lands in the Southeast would yield rates of return on the investment of 10% or greater. The largest opportunities with this rate of return involve the harvest of mature stands followed by the establishment of a new stand with higher rates of growth in terms of volume and value. Only about a fifth of the economic opportunities for regeneration following site preparation on nonstocked or poorly stocked sites had rates of return of 10% or greater. In particular, treatments to establish pine plantations on sites occupied by a large component of upland hardwoods and to naturally regenerate bottomland hardwood stands tended to have lower rates of return than other treatments. Nonetheless, there are over 2.3 million acres of other private lands that could be planted to pine after site preparation for a return on the investment of 10% or greater. Only a small proportion of current economic opportunities are found on pine plantations because of the intensive management already practiced in most of these stands. Of the opportunities that do exist, approximately 75% have rates of return of 10% or greater. Commercial thinning of poletimber accounts for the largest share of these opportunities.

South Central.—Economic opportunities to increase productivity on other private timberland in the South Central region are similar to the opportunities in the Southeast. Around 25 million acres, one-third of the timberland in this ownership, could be treated to increase productivity and yield 4% or more return on the investment. In total, these investments would amount to $2.8 billion. If these investments were made, an additional 1.2 billion cubic feet of net annual growth would be produced. Most of the increase would be in pine growth. This amount equals 68% of current net annual softwood growth and one-third of the net annual growth for all species on other private ownerships.

As in the Southeast, the majority of opportunities are for some form of reforestation or stand conversion. There are, for example, economic opportunities for regeneration following site preparation on 11.9 million acres on other private ownerships. These treatments would add 590 million cubic feet of net annual growth at a cost of $1.8 billion. Most of this area is characterized by cutover oak-hickory stands on sites suitable for pine. High-quality bottomland hardwood sites suitable for natural regeneration represent about 14% of the total economic opportunities.

If all stocking control opportunities on other private ownerships, including commercial and precommercial thinning, were implemented, they would add 330 million cubic feet of net annual growth for an investment of $370 million. Opportunities for release treatments exist primarily on upland hardwood sites and oak-pine sites where growth on crop trees would be enhanced by removal of competition from undesirable vegetation.

One-fourth of the economic opportunities on other private ownerships in the South Central region have rates of return on the investment in forest productivity of 10%

or greater. Although only about a fifth of the area with opportunities to clear, site prepare, and plant has rates of return this high, such opportunities do exist on over 2.5 million acres. Over half of the opportunities in natural pine and mixed pine-hardwood management types have a rate of return of 10% or greater. Most of these opportunities involve either release treatments or other stocking control.

Rocky Mountains/Great Plains

Only about one-quarter of the timberland in the Rocky Mountain and Great Plains regions is in other private ownership, and over half of that area is in the lowest productivity class. Steep slopes, fragile soils, and other environmental factors preclude intensive management practices over large areas of the Rocky Mountain states. Consequently, economic opportunities to increase timber growth on other private lands in these two regions are quite limited.

Idaho and Montana are two states, however, with significant acreage in other private ownership and suitable for commercial timber production. In these two states, approximately 200,000 acres have opportunities to increase timber growth. About half of the opportunities result from reforestation of nonstocked acres. The other half call for release and commercial thinning treatments for suppressed ponderosa pine, Douglas-fir, lodgepole pine, and spruce-fir. Total cost for these treatments would be $24 million. The result would be over 7 million cubic feet of additional softwood growth per year.

Prospective rates of return for these investments are in the range of 4% to 5%. Although there are undoubtedly additional economic opportunities to increase timber supplies in other Rocky Mountain states, more data than was available for this analysis would be needed on areas needing treatment, timber responses to management, and stumpage prices in the region.

Pacific Coast

The Pacific Coast has some of the most productive timberlands in the United States. Only about 20% is in other private ownership. Alaska and Hawaii are excluded from this analysis.

Pacific Southwest.—For this analysis the Pacific Southwest encompasses the state of California. There are economic opportunities to increase net annual timber growth on 1.4 million acres of other private lands. Net annual softwood growth could be increased by over 170 million cubic feet, a 70% increase, at a cost of $185 million. Most of the growth increment would come from harvesting mature redwood and mixed conifer stands and regenerating these stands. Substantial opportunities also exist to rehabilitate Douglas-fir sites overgrown with hardwoods. Commercial thinning or other stocking control of redwood, Douglas-fir, and mixed conifer stands would contribute to the net annual growth increment on about one-fifth of the acres with economic opportunities.

Most recommended treatments for Douglas-fir and redwood stands have average rates of return of 10% or greater. Overall, about 40% of the acres with economic opportunities in the region would earn rates at this level. The net annual growth increment from these treatments would be over 100 million cubic feet.

Pacific Northwest.—The Pacific Northwest has two distinct subregions marked by differences in the timber resource. In the humid and highly productive lands west of the Cascade Mountains in Washington and Oregon, coastal Douglas-fir is the predominant commercial species. In the drier, less productive subregion east of the Cascades in those states, the inland variety of Douglas-fir and ponderosa pine provide most of the timber supplies.

Regionwide, there are economic opportunities on 2.1 million acres of other private timberland. A net annual growth increment of about 364 million cubic feet, almost entirely softwoods, could be obtained with investments totaling $457 million. Virtually all of this increase would be in the coastal Douglas-fir subregion, and 90% of the opportunities in this subregion involve some form of regeneration treatment. These opportunities include planting Douglas-fir on nonstocked sites, sites poorly stocked with hardwoods, or following harvest of overmature stands. Stocking control measures, such as commercial thinning of stands currently overstocked followed by fertilization and precommercial thinning of young stands, also have favorable rates of return. In the ponderosa pine subregion, economic opportunities include planting nonstocked acres, commercial thinning of Douglas-fir poletimber stands, and harvesting mature softwood stands with subsequent artificial regeneration of the site.

Rates of return for treatments in the ponderosa pine subregion tend to average between 5% and 7%. Rates of return in the Douglas-fir subregion run several percentage points higher. Average rates of return are 10% or higher on about one-quarter of the acres in the Douglas-fir subregion. Most of these opportunities relate to commercial thinning and fertilization of Douglas-fir stands.

Prospective Impacts of Implementing Economic Opportunities for Management Intensification

Implementing all of the current investment opportunities on 66 million acres of other private timberlands would greatly impact the age structure, volume, growth rate, and species composition of these forests. A portion of these impacts is already reflected in the baseline projection discussed in Chapter 7. The baseline projection assumes a modest increase in the level of management intensity on other private timberlands over the projection period. To examine the impacts of greater levels of investment on other private lands, an alternative analysis was conducted.

The following sections discuss the investment opportunities already captured in the baseline and the effects of increasing investment levels above those in the baseline. These effects include changes in the forest resource itself and the associated economic impacts, such as changes in stumpage prices and timber product prices and production. There is also an overview of how increased timber production may affect the environment and other forest resources.

Assumptions on Timber Management in the Baseline

Overall, about one-fifth of the current economic opportunities described in this chapter for other private ownerships are already captured in the base projection (fig. 76). Most of the investments in more intensive forest management practices are assumed to occur in the South. This assumption is consistent with the location of the bulk of potential treatment opportunities in the Southeast and South Central regions. Increases in management intensity are also assumed in the Pacific Northwest Douglas-fir subregion because of its inherent productivity for timber and to a lesser extent in the North Central Lake States subregion.

The base projection provides for continuing increases over the projection period in the area of timberland managed as softwood plantations in the regions and subregions mentioned above. Investments above current levels in the management of softwood species in other regions are not expected to occur. Management of hardwood species is expected to continue at low, essentially custodial levels. The following sections describe in more detail the regeneration opportunities that are reflected in the base projection and the difficulty of capturing the effects of stocking control treatments.

Regeneration.—The baseline projection assumes that nonindustrial private owners will plant trees at a rate comparable to that for the recent decade. In total, the acreage of planted pine on nonindustrial private ownerships in the South is projected to rise from 8 million acres in 1987 to 20 million acres by 2040. This increase in area represents a net change. The total number of acres planted to pine in the South is larger than the net increase in planted pine acreage because some pine plantations are harvested over the projection period and other planted pine acres are projected to revert to other forest types or be converted to other land uses.

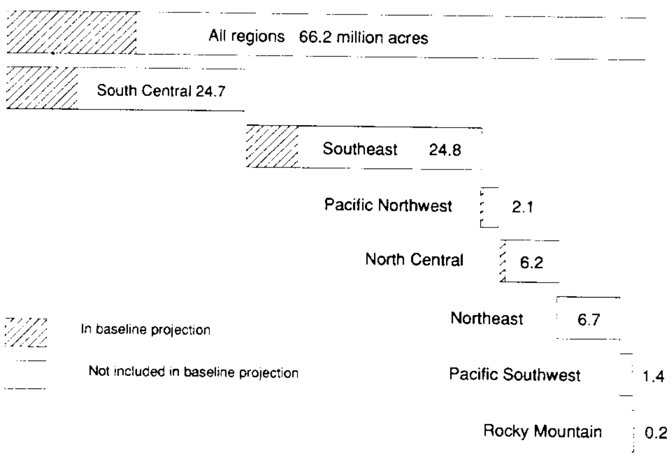


Figure 76.—Acres of other private timberland with investment opportunities and opportunities included in the baseline, by region, with 4% return.

Part of the increase in acreage of pine plantations is due to lands being converted from agriculture and other rural land uses. The remainder represents the projected enrollment of approximately 30% of the 35 million acres of regeneration investment opportunities on existing timberlands in the South.

In comparison to the South, relatively small changes in levels of other private reforestation are projected for other regions of the country. In the Pacific Northwest, about 20% of all regeneration opportunities are projected to be undertaken, resulting in about 300,000 acres of new plantations. In the North Central Lake States subregion, about 10% of the regeneration opportunities are projected to be undertaken. Implementation of these opportunities would result in about 400,000 acres of new red and white pine plantations.

Stocking Control.—Stocking control includes precommercial and commercial thinning and other forms of timber stand improvement. An estimated 24 million acres of stocking control opportunities currently exist on nonindustrial private timberlands. These treatments would increase the proportion of merchantable volume in a stand, alter the species composition, or release growing stock from undesirable competing vegetation. Although stocking control treatments increase the economic returns from timber management, they may have only a minor effect on total stand volume at final harvest. Consequently, the effects on timber supplies of changes in acreage receiving stocking control treatments are difficult to quantify.

The base projection does assume that large areas of softwood plantations on other private ownerships, especially in the South and the Pacific Northwest, will be more intensively managed than they are now. By the end of the projection period, the area of softwood plantations where thinning is part of the management regime will double in the Pacific Northwest Douglas-fir subregion and increase fourfold in the South. In the opportunities analysis, part of the growth increment attributed to stocking control treatments is based on a similar assumption that existing stands are regenerated after final harvest and receive appropriate stocking control treatments through subsequent rotations. Thus, for purposes of this analysis, it was not practical to separate the effects of stocking control treatments from regeneration treatments in the base projection or the alternative analysis of increased levels of investment.

Increasing Investment Levels above the Base Projection

As described in preceding sections, there currently exist substantial economic opportunities to increase timber growth on timberland in other private ownership. Much of the discussion focused on the opportunities with average rates of return of 4% or higher.

For many reasons, it is unlikely that all of these opportunities will be implemented. Some are likely to be implemented, however, if current management trends on other private lands continue. This portion of the opportunities has been incorporated in the base projection. Capturing all of the remaining opportunities would require investments far beyond the investment levels common today and would have significant impacts on timber product markets and production.

Analyzing the impacts of implementing additional timber management opportunities presents several difficulties. First, the analysis of economic opportunities was made with the base projections of stumpage prices (see table 111). As additional investments are implemented, timber inventories increase, causing stumpage prices to fall. This reduces the economic incentive for implementing opportunities. Second, as discussed earlier, the effects on timber supplies of intermediate stand treatments are essentially excluded. Finally, although the opportunities to increase timber growth are defined in terms of current stand conditions, regeneration and/or stocking control treatments would in all likelihood be implemented over an indeterminate number of years in the future.

To provide some indication of the impact of increased investments in forest management despite these limitations, an alternative scenario was structured which assumed that regeneration opportunities with a rate of return of 10% or greater were implemented uniformly over the projection period. Investments in forest practices beyond what is in the base will need to be extremely attractive (or highly subsidized) in order to be adopted (Brooks 1985, Cubbage and Haynes 1988). Opportunities with a 10% rate of return are likely to remain attractive even if prices do not rise to the levels in the base projection. Almost all of these opportunities are in the South. These investments would increase the net gain in pine plantations in the South in the base projection by about 50%.

Forest Resource Impacts

The impacts of increased investments on other private timberlands are substantial. Softwood timber supplies (harvests), net annual growth, and inventories are all higher than the base projection. Softwood inventories are 8.1% greater in 2040 for private timberlands in the South. The pattern for growth increases, inventories, and harvests illustrates how timber markets function. Increases in investment first result in larger growth increments. This leads to increases in inventories as industrial capacity slowly responds. Finally (and in later decades) harvest increases as capacity rises and shifts to the South to take advantage of the increase in raw materials. The impacts on the softwood forest resource are primarily located in the South where the bulk of the private timberland investment opportunities are located. Additional impacts occur in other regions as industrial capacity shifts to the South. In general the economic impacts are associated with increases in softwood harvests (see table 124). By 2040, harvests in the South have increased by 2.2% but stumpage prices have fallen by 20%. Lower stumpage prices lead to higher solid-wood production and consumption. By 2040, increased lumber production also leads to a 20% reduction in softwood lumber imports from Canada.

Economic Impacts

As a result of the increase in inventories and harvests, stumpage prices for sawtimber are reduced below those for the base in all regions. This is most evident in the South where stumpage prices are 10% lower in 2010 and 20% lower in 2040. Stumpage prices in the Pacific Northwest Douglas-fir subregion are reduced by 12% by 2040. These lower stumpage prices lead to lower lumber prices (3.9% by 2040).

In response to lower lumber prices, softwood lumber production rises and by 2040 is 5% higher. This increase in production comes at the expense of softwood lumber imports from Canada which drop by 2 billion board feet. Softwood plywood production and softwood plant byproduct consumption are also increased.

A majority of the economic opportunities in the South involve the conversion of oak/pine and upland hardwood stands to pine plantations. Implementation of the regeneration opportunities in the alternative scenario results in a 38 million cubic feet decline in the hardwood inventory in the South by 2040.

Impacts on the Environment and Other Renewable Resources

Intensification of timber management would be expected to have wide-ranging effects on the forest environment and other renewable resources. Because of the vast differences in timber types and local environmental conditions, along with the wide variety of timber management activities, it is not possible to specify or quantify all of the positive or adverse effects. These impacts, however, may be discussed in a general way. Most adverse impacts can be mitigated through careful planning and faithful execution of the plan.

Timber management activities, in particular timber harvesting, provide the means to greatly alter not only the trees but the understory vegetation for a forested area. Any type of timber removal will alter the amount of light and moisture reaching the forest floor, which in turn will have an effect on the understory vegetation. The resulting changes may be either positive or negative depending upon the viewpoint of the landowner or forest user. Manipulation in the form of intensive management will generally improve the health of the forest vegetation, since reduction of stand densities and regeneration of stands before they begin to lose vigor will help minimize insect and disease losses.

For harvest activities, as well as some slash disposal and site preparation activities, the potential exists for considerable soil disturbance. The degree to which this disturbance occurs depends upon many factors, such as the silvicultural operation, the soil type, topography, precipitation amount, and the type of skidding equipment used. Roadbuilding to provide access to harvest areas can be a major source of soil movement and potential erosion. Eroded soils frequently end up in streams, raising the turbidity of the water and leading to sediment deposits in other locations.

Access becomes easier for hunting, fishing, and many other types of recreation with road construction for timber harvesting. Adverse recreational impacts may occur, primarily as a reduction in the esthetic quality of the forest area for viewing, hiking, or camping. In many instances, landscape vistas can be improved by manipulation of some of the vegetation.

Vegetation removal can have a major effect on the water resource both directly and through its effects on the soil. Water yields are increased with harvesting activities, but the amount and duration of the increase depends upon site characteristics, precipitation, and the vegetation removed. Stream temperatures can be raised by the removal of the riparian cover that provides shade. In most instances, an increase in water temperature is not a favorable impact on either the fisheries resource or on water quality for human domestic consumption. Fish are also very sensitive to dissolved oxygen concentrations in streams. Severe reductions in oxygen concentrations due to soil particles from erosion and accumulation of slash or other forest residue in streams may be fatal to fish, even if the reductions occur for only brief periods.

Herbicides used in timber management activities involve special water pollution and safety concerns. Many of the herbicides used in forestry are the same as those used in the agricultural community, but the quantity applied per acre and the frequency of application is almost insignificant when compared to the agricultural community.

Changes in vegetative type inevitably affect the kind and amount of habitat available for different wildlife species and thus influence the wildlife community composition. Species dependent on climax forests will become less common following harvest while species dependent on early seral plant communities will become more common. Many species are dependent on a mosaic of plant communities which will provide their needs for both cover and forage. A forest composed of a mosaic of habitats will provide for the largest diversity of wildlife species, and this mosaic may be created through carefully prescribed timber harvest.

Invertebrates are also affected by management activities. Soil disturbances, such as compaction and altered infiltration rates, can cause habitat changes that dramatically affect the invertebrate populations of forest soils. This population, in turn, affects the availability of food for amphibians, reptiles, small mammals, and birds.

Concern about the environmental impacts of forest management activities has led to an increase in state forest practice regulation over the past two decades. Federal water pollution control statutes have been a major impetus behind efforts to control timber harvesting activities and other activities near streams. Controls range from voluntary compliance with guidelines developed as "best management practices" to mandatory legal restrictions. In addition to water quality, forest practice regulation may address areas such as reforestation of harvested lands, prescribed burning and treatment of slash, pesticide and herbicide applications, and occasionally management of wildlife habitat and esthetic quality (Henly and Ellefson 1986). Mitigation measures to avoid adverse environmental impacts will continue to be an increasingly important aspect of forest management as forest practices regulation becomes more widespread and comprehensive.

FACTORS AFFECTING INVESTMENTS IN FOREST MANAGEMENT ON OTHER PRIVATE LANDS[42]

The preceding section of this chapter described the substantial opportunities that currently exist to increase timber growth through investments in forest management, in particular on other private lands. Although this analysis indicates that landowners and society can expect positive financial returns on these investments—in many cases returns of 10% or more—the portion of these investments that will actually be made is open to speculation. An array of ownership objectives and institutional factors affect decisions by other private landowners on how to manage their forests.

Management Objectives of Owners

Private individuals and organizations other than forest industry own roughly three-fifths of the Nation's timberland and number more than 7 million. Seventy percent of these owners have less than 10 acres of timberland, but these small acreage holdings account for only about 4% of the total acreage in this ownership (Birch et al. 1982). Holdings larger than 100 acres encompass about 75% of total nonindustrial private forest land and are the source of most of the timber harvests from this ownership category.

Nonindustrial private owners are a very heterogenous class of forest owners. Many of these owners manage their forest land for resources or benefits other than timber. Timber management may be perceived as secondary to or in conflict with other benefits, such as recreation, wildlife, or scenic beauty. Nonetheless, nonindustrial private owners are often considered to hold the key to increasing the productivity of the forestry sector and thereby increasing the Nation's timber supply. Over the past three decades, the proportion of total national timber supplies from these lands has declined slightly, from around 57% to just over one-half. Other private owners, however, accounted for almost two-thirds of the large increase in harvests over the last decade (tables 118 and 119).

[42]*Material in the sections on management objectives of other private owners, market incentives and barriers to forestry investments, and tax policies is based on Yoho (1988).*

Other private owners who do not rule out timber management as an objective still cover a wide spectrum of interest in making investments toward that end. The least interested owners could be classified as custodial owners or sideline investors. Custodial owners would include individuals or groups simply holding timberland pending some further disposition, such as heirs waiting to sell forest property. Sideline investors typically own forest land as an appendage to another asset, such as a farm or residential property. Both types of owners are unlikely to give much attention to the investment opportunities on their forest land.

Some forest property may be acquired by individuals or organizations with an interest in speculative investment. Speculators usually try to acquire forest land with good chances for a windfall appreciation in property value in excess of increases due to timber growth. Typically, investment strategies for speculators do not call for increased investments to promote growth.

On the other hand, many other private owners are interested in investments in timber management. For some, managing their timberland is a hobby or second vocation. These owners may be motivated to maintain a well-managed forest as much for the personal satisfaction and recognition associated with stewardship as for economic returns. Finally, there is some fraction of other private owners who will behave as true investors and who could be expected to respond to opportunities based on economic criteria alone.

At any given point in time, only a portion of other private timberland owners are managing their lands for timber production. In addition, ownership tenures for forest land are often quite short in relation to the time it takes for trees to grow to maturity. A 1978 survey of landowners nationwide, for instance, found that over 40% of the forest land had been acquired by the present owners within the previous 20 years (Birch et al. 1982). Control of individual forested tracts during the course of a rotation, therefore, may pass into or out of the hands of individuals or organizations with an interest in timber management.

For forest land owners willing to consider timber management, the likelihood of investment may be affected by their perceptions of market incentives and barriers to timberland investments.

Market Incentives and Barriers to Forestry Investments

Expectations for Financial Returns and Liquidity

Most forest owners appear to have realistic but vague and rather conservative expectations as to the financial returns they can expect from their forest properties. It seems to be widely recognized that forests generally represent long-term, modest yielding and generally low liquidity investments.

Many forest owners, however, would have great difficulty in translating their expectations of growth, harvest and stumpage values into an anticipated rate of return on investment. Generally, only the most sophisticated owners, such as those who seek the help and advice of professional foresters, have rate of return estimates in mind.

Forest owners often have low to modest financial expectations for their forest properties partly as a result of overestimating prospective losses due to natural risks. Most owners perceive the risk from fire, insects and disease to be considerably greater than national studies have shown. Also, many nonindustrial private owners are only vaguely aware of the possibilities of partially recovering losses of forest capital by salvage.

Institutional investors, on the other hand, who are accustomed to handling client accounts with investments in equities (common stock), bonds (government and corporate), commercial real estate and farm land, appear to be quite demanding and exacting in terms of the rate of return outlook they would require before investing their client's money in a commercial forestry venture. Institutional investors look for a premium for higher perceived risk and lower apparent liquidity in comparison with the return they would expect to earn on other investments, such as commercial real estate.

Forests normally represent very long-term investments and require planning horizons far beyond those employed by average investors. Forest investors often must plan on investment paybacks beyond their own life expectancy. Given such long time periods, the cost of capital becomes even more significant as the deciding factor in evaluating the profitability of forestry investments.

The low liquidity problem is particularly acute in the first half of the life of the investment. This situation discourages established owners and prospective new investors from developing young forests because significant losses could result if they had to be sold before about mid-rotation age. Wider acceptance of the discounted cash flow method of valuing forestry investments might result in better recognition of the value of young stands.

Portfolio Balance

Forestry investments, however, may have other attributes which make them attractive to large investors and investment managers. On the basis of a few and not very exhaustive studies using portfolio analysis, forestry investments appear to be somewhat countercyclical to the earnings performances of bonds (corporate and public) and corporate stocks. This results in lower overall risk for an investment portfolio of which timber is a part, thereby improving total portfolio returns. If further investigation demonstrates this to be the case, it would go a long way in offsetting forestry investments' modest rates of return, long payback periods, and lack of liquidity.

Capital Requirements

Many owners acquired their forest properties by gift, inheritance or other passive means and, thus, are not likely to view their forest as a package of investment opportunities. Such owners are often land rich and capital poor; hence, they are not financially able to respond to incremental investment opportunities on their own lands.

Risk and Uncertainty

The long-term aspect of forestry investments tends to magnify the real and perceived risks and uncertainties associated with them. The prospects envisioned by forest investors for loss due to fire, insects, and disease constitute powerful deterrents to increased private investment in forestry. But, the availability of better information on losses from such factors and the development of diversification strategies by forestry investors could, in time, lessen the seriousness of this problem.

Prices

Future price trends for forest products and standing timber always have been, and will continue to be, one of the basic worries of forestry investors. In recent years great strides have been made by forest economists in formulating price projections through the development of sophisticated national and regional models by which timber supply and demand can be projected many years into the future. But these models are not yet capable of fully incorporating rest-of-the-world impacts on the United States. Possible impacts of foreign competition, both in domestic and overseas markets, on timber prices in general are a continuing concern.

The other price problem for many forest owners and investors is the matter of local prices. Projections of regional and national price trends may not be applicable to local markets where tree farmers sell the timber stumpage they produce. Studies have shown timber stumpage prices are strongest in areas with the most active competition among buyers. Interest in investment in timber growing also tends to be strongest in areas with active markets and with prices in line with, or above, regional averages. Often, however, forest owners sell in local markets where only one or two buyers are active. One mechanism for making the markets for standing timber behave more competitively has been to have better market and price information more readily available to all timber sellers.

Landowner Assistance and Incentive Programs

Providing assistance to nonindustrial private forest land owners to encourage production of timber and other benefits from their lands has long been recognized as an important objective for both public and private policies and programs (Cubbage and Haynes 1988). A substantial portion of the activities in regeneration, improvement, and protection of timber stands, as well as improvements in harvesting and utilization, on farm and other private ownerships is a result of a range of educational, technical assistance, and financial incentive programs. In addition, many private forest land owners have benefited from federal and state tax policies that reduce tax liabilities associated with owning and managing timberland.

In 1978, Congress passed three related acts to improve management of timber and other forest resources through better coordination among existing programs of education, technical/financial assistance, and research. These acts are: the Renewable Resources Extension Act (P.L. 95-30), the Cooperative Forestry Assistance Act (P.L. 95-313), and the Forest and Rangeland Renewable Resources Research Act (P.L. 95-307).

Education

Educational programs inform landowners of opportunities for protecting and managing their lands and of sources of assistance that are available. The Renewable Resources Extension Act (RREA) resulted in expanded programs by the Cooperative Extension Service and associated colleges and universities in forest land management and four other areas (rangeland management, fish and wildlife management, outdoor recreation, and environmental management and public policy). Federal RREA funds act as seed money for these programs; two-thirds of the total funding comes from state and local contributions. In 1986, about 68% of the $2.4 million appropriation for RREA went for forest land management (USDA Extension Service, n.d.). Forest land management programs include not only education of forest owners, but also programs for improved harvesting, continuing education for forestry and related professionals, improved utilization by forest product manufacturers, and increased public awareness and understanding. Extension programs have been one of the primary channels for disseminating new research findings to forestry professionals, landowners, and wood processors.

In addition to extension programs, there are also a growing number of public and private programs that publicize the benefits of forest protection and management by providing recognition to landowners who adopt sound forestry practices. Forests selected by these programs often serve as examples or demonstrations of management opportunities for other landowners and the community. The American Tree Farm System, a program of the American Forest Foundation administered by the American Forest Council, is one example. Nationwide there are more than 61,000 tree farms encompassing 89 million acres certified for the program. Most of the tree farms are in the South and in the North. The TREASURE Forest program operated by the Alabama Forestry Planning Committee, a coalition of state and federal agencies, with cooperation from forest industry, environmental and landowner groups, is another example.

Various studies have shown that forestry education and technical assistance for nonindustrial private landowners have resulted in adoption of improved management techniques, increased returns to landowners from their timberlands, and favorable benefit-cost ratios for society.

Technical Assistance

Technical assistance programs, usually concerned with the preparation and implementation of management plans, provide direct on-the-ground assistance to landowners on how to manage their forests to achieve a variety of objectives. These objectives may include not only timber production but also wildlife habitat improvement, esthetics, and soil and water protection.

State foresters perform the field work for state programs and for programs administered by the Forest Service in cooperation with state forestry agencies. The Soil Conservation Service also cooperates with state forestry agencies and extension personnel when developing management plans for conservation practices on farms that involve forest practices. Private sector programs include landowner assistance programs provided by individual companies in the forest products industry and a wide range of services provided to landowners by consulting foresters.

In 1978, authorizations for a variety of cooperative programs between the Forest Service and state forestry agencies were consolidated by the Cooperative Forestry Assistance Act. The Rural Forestry Assistance section of the act authorizes federal financial and technical assistance to state forestry agencies for nursery production and tree improvement programs; reforestation and timber stand improvement activities on nonfederal lands; protection and improvement of watersheds; and programs to provide technical forestry assistance to private landowners, vendors, forest operators, wood processors, and public agencies.

In the private sector, the largest share of technical assistance is provided by consulting foresters. In return for fees paid by the forest landowner, consulting foresters provide detailed management advice, market forest products, and arrange for equipment and labor to get forestry work done. According to the Association of Consulting Foresters, there are some 2,500 consulting foresters in the United States, nearly double the number in 1976.

Landowner assistance programs provided by individual companies in the forest products industry have also been growing rapidly. This assistance is usually provided in return for the opportunity to bid on the landowner's timber when he decides to sell. Technical assistance is usually free and other practices provided at cost. Over the past decade these programs have been increasing in the South, declining somewhat in the West, and are stable in other sections.

Financial Assistance/Incentives

Federal funding for forest management assistance peaked in the years immediately following passage of the 1978 Cooperative Forestry Assistance Act. In recent years, this funding has declined sharply. Federal contributions (in constant 1982 dollars) between 1983 and 1988 averaged only half the level for the period 1978–82. Federal funding for forest management and utilization programs in 1987 was approximately $10 million.

In general, state funding for the programs authorized by the Cooperative Forestry Assistance Act has far exceeded the requirements for matching federal funds. In recent years, for example, $9 out of every $10 expended for nursery production, tree improvement, and forest management assistance have come from state sources. State appropriations have not increased sufficiently in many areas, however, to make up for the decline in federal support (Lickwar et al. 1988).

Most financial assistance programs for forestry involve cost sharing, whereby federal or state governments pay a portion of the cost of establishing and maintaining timber stands on private lands.

The Forestry Incentives Program (FIP) is the principal federal cost sharing program aimed at increasing timber production by assisting nonindustrial private landowners with planting, site preparation for natural regeneration, and timber stand improvement. Agricultural Stabilization and Conservation committees for each state and county, in consultation with state forestry agencies, establish a cost share rate up to a maximum of 65%. In counties not designated for FIP or where all FIP assistance has been allocated, cost sharing may be available under the Agricultural Conservation Program (ACP). Although the primary purpose of this program is soil and water conservation, cost shares of up to 75% (80% for low-income participants) may be authorized for reforestation and stand improvement. Actual cost shares are set by state and county committees in the same manner as FIP. Actual cost shares for FIP and ACP are often around 50%.

In 1986, FIP paid out $11.3 million in cost shares for treatments on over 228,000 acres (USDA Agricultural Stabilization and Conservation Service 1988a). Over three-quarters of this assistance went to landowners in the South. Another 12% went to landowners in the North. Under ACP, approximately $6.4 million in cost shares were spent for forestry practices on 126,000 acres (USDA Agricultural Stabilization and Conservation Service 1988b). Slightly over half of this assistance went to private landowners in the South, 28% to the North, and 16% in the West.

In the late 1970s and early 1980s, between 40% and 50% of all tree planting on other private ownerships was cost-shared by FIP or ACP. Although around 250,000 acres per year are being planted with financial assistance from FIP and ACP, these acres now represent a smaller proportion of reforestation activity on nonindustrial lands.

A number of states also have cost share programs, supported with state and/or industry funds, or provide other assistance to landowners for reforestation, such as free seedlings. Many of these programs have been established within the last 10 years and are serving an increasing number of landowners. Between 1981 and 1985 in the

South, for example, the number of acres planted with aid from state cost share programs more than doubled and accounted for more than one-third of all acres regenerated with cost share assistance in 1985 (Royer 1988).

Cost sharing has been found in a number of studies to encourage investments in forestry practices. An evaluation of the 1979 Forestry Incentives Program (Risbrudt and Ellefson 1983) attributed to the program an additional 1.3 billion cubic feet of timber growth over the first rotation and an average real internal rate of return of over 8% for public and private investments under the program. An analysis of reforestation decisions by landowners in the South who had harvested timber concluded that awareness of cost sharing programs increased the likelihood of reforestation by 19% (Royer and Moulton 1987).

Some of the increases in reforestation on other private lands since 1985 are attributable to the Conservation Reserve Program, established under the Food Security Act of 1985. Under this program, farmers receive annual rental payments (established by bid) for 10 years and payments of up to 50% of the costs of establishing trees or grass on the highly erodible acreage placed in the reserve. This financial assistance, combined with the often favorable returns from planting pine on marginal cropland in the South (discussed earlier in this chapter), greatly enhances the economic incentive for farmers to convert highly erodible cropland to forestland. Landowners are able to stock the growth that occurs on the trees during the 10-year establishment period while they are receiving the annual rental payment. In some cases, the trees are ready for harvest with only 5 more years of growth. From first acceptance of bids in 1986 through mid-1988, over one and a half million acres had been approved for tree planting under the Conservation Reserve Program, with over 90% of these acres in the South.

Tax Policies

Tax incentives, perhaps more correctly called special tax benefits, have been applied in forestry for three basic purposes from which it is presumed that society as a whole will gain:

1. To encourage private forest landowners to invest in activities to increase timber supply and to encourage the movement of capital from outside sources into forestry, thereby overcoming an inherent investor bias.
2. To compensate forest owners for the nontimber values which society derives from the maintenance and management of private forest holdings.
3. To provide equity to forest owners for the biases that the tax system imposes on them essentially due to the long-term nature of such investments.

Tax incentives applicable to forestry investment are found in two general categories of the tax system—the ad valorem general property tax and the income tax system, mainly the federal income tax. General property taxes are levied on forest ownerships by local jurisdictions under the authority of the states in which the properties are located. Such taxes may be levied on the land and timber together, or separately. Income taxes, on the other hand, are levied on forest owners, be they corporate, individual or other, and are based on the income derived from the harvest of timber and other products. Forestry income tax incentives are mainly concerned with the classification of income and the rate at which income is taxed, plus the handling of costs associated with generating that income.

Property taxes.—The general property tax as ordinarily administered is thought by many forest economists to be very discouraging to the maintenance of intensive investments in forestry on private lands. The reason for this concern is the fact that the tax is levied annually against the timber growing asset which is not likely to produce a significant income until harvested, usually after a period of many years.

Various tax deferral alternatives for the annual property tax on standing timber have been developed to neutralize the forest disinvestment incentives which have been mentioned above. Under a forest yield tax, for example, owners in effect are permitted to defer the annual ad valorem taxes on the standing timber until it is harvested. However, the land on which the timber is growing continues to be taxed annually according to the ordinary provisions of the general property tax or, in many states, under one of several special modified tax systems applicable to the land, such as use value taxation or differential rate taxation.

Many private forest owners, however, have shied away from electing to place their properties under a tax deferral arrangement on the assumption that such action would tend to cloud the title to the property and thereby impair its liquidity. In addition, some recent studies have shown that the most prevalent reason for nonindustrial landowners not enrolling their properties under special tax deferral programs is their refusal to accept the accompanying restrictions on use and management of their properties, such as permitting open access for hunting, etc. Surveys have also shown that a substantial portion of nonindustrial forest owners in states with optional forest yield tax laws are likely to be unaware of the fact that such an alternative is available to them.

In contrast to the optional yield tax programs, in most states the majority of eligible owners have enrolled their properties under the special modified property tax systems available for forest land when these are operated apart from yield tax systems. These modified property tax schemes apparently provide more forest investment incentive than optional yield tax laws.

Income taxes.—Prior to passage of the Tax Reform Act of 1986, forest owners and investors had come to rely on the ability to classify income originating from timber growth, as well as income which arose from appreciation in the value of other capital assets over an extended period, as long-term capital gains. Individuals were allowed to exclude 60% of long-term capital gains from taxable income. Likewise, forestry investors had grown accustomed to writing off current forest operating, maintenance and protection costs incurred in growing new stands of timber, against current ordinary income from any source. Initial stand establishment costs had to be capitalized and, thus, could only be recovered over a period of years and perhaps not until the stand was harvested.

With the advent of the Tax Reform Act of 1986, the above described economic climate for long-term, modest yielding forestry investments has changed significantly. Differential tax rates for all types of long-term capital gains income have now been completely phased out. Tax reform and the ensuing "passive loss" rules, as developed by the Internal Revenue Service, have restricted forest owners who do not qualify as an "active business" from charging annual forest management costs against certain types of current income. Forest owners still have the attractive option of using 10% of the first $10,000 of qualifying reforestation expenditures per tax year as a tax credit. They may also amortize 95% of the total qualifying amount as a series of annual deductions against income over a period of 84 months.

Other tax policies.—In addition to the limited tax credit, other advantageous tax provisions, which are not restricted to forestry-related activity, still remain as important considerations to forestry investors.

One provision has to do with estate building. When a forest owner or investor dies, the estate, after exemptions and deductions, is taxed on its fair market value under provisions of the federal estate tax laws. However, gains in the value of the estate, including the forestry portion, as measured between the owner's investment basis in the property and its fair market value at the time of death, are not taxed as gains for income tax purposes to the deceased. This is extremely important to many individual nonindustrial forest owners who make large investments in forestry because their primary motive for doing so is to build an estate for their heirs.

Many of these tax advantages which benefit forestry estates under the federal provisions, however, tend to be offset by state death tax laws. This is due to the liberal exemptions and credits at the federal level which are not available in quite a few states.

Another advantageous tax provision for timber owners, which still remains after further changes made by the 1987 Tax Act, permits any forest owner to utilize the installment sale method of leveling timber sale income over a period of tax years. This act precludes the tax reporting advantages of installment sales by sellers of real property who are considered to be in such a trade or business, but an exception is made for sellers of farm property and timber.

The long-term impact on forestry investment activity resulting from the substantial changes made in the tax code in 1986 is not yet apparent. Some analysts believe that forest investors will adjust to the changes so the impact will be minimal. Others are finding that owners are cutting back on the extent of their investments in intensive practices because many such investments have been made submarginal by the impact of the tax code changes on after-tax income. Since investments in forestry must be based on long-term considerations, concern about possible changes in the tax laws creates an uncertainty that affects investor confidence regarding the economic outlook for such investments.

CONCLUDING OBSERVATIONS

In summary, programs of education, technical assistance, and financial incentives have been designed over the years to encourage investments in timber management by nonindustrial private owners. It remains to be seen whether the investments made over the past decade, including the substantial increases in tree planting, are sufficient to turn around the recent decline in productivity on other private lands noted at the beginning of the chapter. Due to the large area of timberland held by other private owners, future gains in productivity for the Nation's timberlands as a whole will continue to be heavily influenced by the status of management on these lands. Although many broad generalizations about stand conditions, costs, prices, and other factors affecting timber management decisions had to be made for the analysis in this chapter, it is clear that substantial opportunities to increase forest productivity on other private lands exist today. These investments, if made, would generate significant increases in timber growth at a favorable rate of return.

CHAPTER 10. OPPORTUNITIES TO CHANGE TIMBER DEMAND THROUGH ALTERED TIMBER UTILIZATION

Opportunities to meet rising demands for timber products by increasing net annual timber growth are discussed in the preceding chapter. Utilization improvements can also aid in meeting rising demands by increasing the efficiency of harvesting, processing, and end use of wood and fiber products. But utilization improvements may also increase demand for timber by reducing wood product cost relative to the cost of nonwood products or by developing new products or end uses. These improvements, in general, increase the economic contribution wood-using industries can make to the economy when using a limited timber base.

This chapter discusses opportunities for utilization improvement that will (1) increase efficiency of wood use, (2) reduce the cost of wood products and the cost of using wood in applications, and (3) provide new or improved wood products or wood use applications. A key purpose here is to propose and explain technology-influenced projections of (1) costs for harvesting, softwood lumber processing, plywood processing, nonveneered structural panel processing, and paper/paperboard processing; and (2) product recovery factors for softwood lumber, panels, and paper/paperboard. Projections of processing costs and product recovery are shown in Chapter 6. These projections are used in the various projection systems to project timber consumption and prices shown in Chapter 7. In this chapter, the first section reviews recent trends in improving wood utilization technology. The second discusses and projects the impact of prospective improvements in wood utilization. These technology projections are used in the base timber market projections discussed in Chapter 7. The third section discusses and evaluates the role of research in changing wood utilization technology.

RECENT TRENDS IN IMPROVING WOOD UTILIZATION

Improvements in Timber Stand Utilization

In recent years there has been substantial improvement toward greater utilization of all timber on a harvest site and greater utilization of sources other than growing stock (table 76). This greater utilization of growing stock[43] has been aided by improvements in harvesting, use of a broader range of wood quality in products, and new products that can be made from timber sources other than growing stock. Use of other sources of timber other than growing stock sources has also improved with greater use of whole tree chipping, integrated harvesting, and increases in fuelwood harvesting. Despite the considerable improvement in use of growing stock and other timber sources for products, logging residue left on sites (including growing stock and other logging residue sources[44]) is still one-quarter as large as the amount of roundwood removed. Opportunities for increased utilization of timber on harvest sites still exist.

Improvements in Product Recovery from Roundwood and Residue

Improvement in utilization of timber sources has been accompanied by improvement in product recovery from roundwood and from residue. Between 1952 and 1976 the residue left unused at mills declined from 13% to 4% and declined to 2% in 1986. By 1986 virtually all roundwood was made into products or converted to energy. The percentage of roundwood and mill residue converted to solid products or delivered to pulpmills increased from 68% to 90% between 1952 and 1976 due to increased sawmill and plywood/veneer mill product recovery, and increased use of mill residue for pulp, and panels. But the proportion declined to 88% in 1986 partially as a consequence of increased demand for fuelwood.

There are three trends that explain the improvement in roundwood conversion. First, product recovery has improved for lumber and plywood processing. Second, products with higher average recovery have replaced those with lower recovery. That is, plywood has replaced lumber in many uses, nonveneered panels are challenging plywood in structural uses, and composite lumber products are replacing lumber in selected applications. Third, there has been progressively more complete use of mill residue for composite products and pulpwood.

The relative importance of recovery improvements is greater for processes that consume more wood material. Sawmills and pulpmills process roughly the same amount of wood material—7.1 and 7.6 billion cubic feet in 1986 (fig. 77, table 129). Pulpmill furnish includes both roundwood and mill residue. Sawmill input is 24% hardwood. Homes and industries burn 4.5 billion cubic feet of wood for energy. Plywood and veneer mills process 22% as much as sawmills. Their input is 7% hardwood. Particleboard mills, oriented strand board/wafer board mills and miscellaneous industries use about 16% as much wood as sawmills, much of which is residue.

The degree of improvement in these process categories is suggested by specific statistics. Many sawmill studies have shown improved lumber recovery factors (LRF). For example, in the Pacific Northwest-West softwood LRF is estimated to have improved from 6.67 to 7.87 board feet per cubic foot between 1952 and 1985 (table 88). Table 129 suggests that in 1986 sawmills required 2.36 cubic feet of timber to be harvested for each cubic foot

[43]Other sources includes salvable dead trees, rough and rotten cull trees, trees of noncommercial species, trees less than 5 inches dbh, tops and roundwood harvested from nonforest land (e.g., fence rows).

[44]Other logging residue sources include material sound enough to chip from downed dead and cull trees, tops above the 4-inch growing stock top and trees smaller than 5 inches. It excludes stumps and limbs.

of lumber produced—an overall conversion efficiency of 42%. In preparing projections of timber consumption and prices in Chapter 7, the TAMM model used an estimate of 2.04 cubic feet of timber for each cubic foot of lumber produced—an overall conversion efficiency of 49%. The 49% estimate is more in line with estimated sawn wood conversion efficiencies for Canada and European countries (UNECE/FAO 1987).

Softwood plywood recovery factor in the Pacific Northwest-West is estimated to have improved from 12.5 to 14.5 square feet (3/8 inch basis) per cubic foot between 1952 and 1985 (table 89). Table 129 and estimates used in the TAMM model indicate that in 1986 softwood and hardwood plywood/veneer mills converted 50% of veneer log volume to plywood or veneer. Of all roundwood going into lumber and plywood/veneer production the proportion going into plywood production increased from 5% in 1952 to 19% in 1976 and then declined to 18% in 1986.

Nonveneered structural panel production, which currently recovers 55% to 60% of wood input, has grown from 0.8% of structural panel production in 1976 to 15% in 1986. Not only do nonveneered structural panels recover more of wood input, they use a larger proportion of more abundant hardwoods and smaller diameter logs than the average logs required to make lumber or plywood.

This is only a partial list of the process and product trends that are improving the proportion of wood input

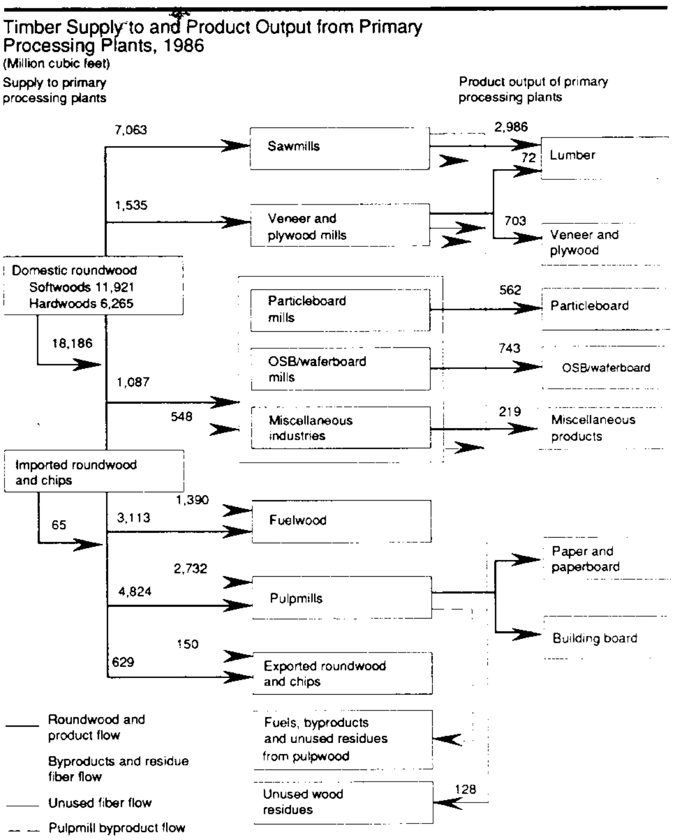


Figure 77.—Timber supply to, and product output from primary processing plants, 1986.

that ends up in solid-wood products. There are also improvements that increase the quality of lumber and panels from given timber or retain quality when using lower cost timber.

The use of wood (both hardwoods and softwoods) in making all paper, paperboard and related products increased from 1.08 to 1.21 cords per ton of paper between 1952 and 1986. This overall trend masks four important underlying trends. First, use of pulpwood per ton of paper and board has increased largely because of greater use of woodpulp and less use of waste paper attendant with the production of a greater proportion of high strength and lightweight paper and board products. Between 1952 and 1986 woodpulp use per ton of paper and board increased 14% and wastepaper use decreased 36% (table 91). Second, pulpwood use per ton of pulp actually declined between 1952 and 1986 from 1.6 cords to 1.5 cords. Third, use of mill residue as part of the pulpwood mix has increased from 25% in 1962 to 36% in 1986. Fourth, the proportion of hardwood in the pulpwood mix has increased from 14% in 1952 to 25% in 1976 and 31% in 1986. The shift to hardwoods has occurred because of technology developments allowing greater use of shorter hardwood fibers.

Changes in the End Use of Wood Products

Improvements in recovery of products from roundwood and residue have been accompanied by improvements in the efficiency of wood use in construction, manufacturing and shipping, as well as development of new wood products or applications for wood that have replaced nonwood products (Bowyer et al. 1987). Examples of end-use efficiency improvements include prefabricated roof trusses which save up to 30% of wood requirements over conventional roof systems. Roof trusses have expanded from less than 1% of residential roofing in 1952 to 77% in 1976 and more than 90% in 1986. Long spans are possible and reduce the need for interior load bearing walls, costs can be held down on assembly lines in manufacturing plants, and erection time is reduced at construction sites. An example of one wooden product being used to replace another wooden product has been the use of medium density hardboard siding in place of softwood lumber. This product has also replaced plywood and aluminum siding. The market share of hardboard siding peaked in 1983 at 31% and has declined to 25% in 1985. Finally, vinyl siding is an example of a nonwood product competing with a wood product. Vinyl siding was first introduced in 1957 but did not exceed 1% of the siding production until 1963. By 1985, improvements in quality, particularly regarding the fading of the finish, and reduction in cost increased its market share to 16% of siding production.

An example of a new use for wood has been the development and use of residential wood foundations. Since the building of a number of demonstration homes in 1969–71 the number of new homes using wood foundations increased to about 20,000 per year in 1984 or about 1% of new homes.

Table 129.—Source and utilization of roundwood in primary processing plants in the United States by softwoods and hardwoods, 1986.

Product	Total	Residue[1] from solid products	Sawlogs	Veneer bolts and logs	Pulpwood, roundwood and whole-tree chips	Pulpwood chip imports	Miscella-neous industrial	Fuelwood
	Million cubic feet, solid-wood basis, excluding bark							
Supply to primary processing plants								
Roundwood products from U.S. forests								
Softwoods	11,921	—	5,980	1,433	3,095	—	868	545
Hardwoods	6,265	—	1,668	127	1,683	—	219	2,568
Total	18,186	—	7,648	1,560	4,778	—	1,087	3,113
Imported roundwood and chips								
Softwoods	58	—	10	0	12	36	—	—
Hardwoods	7	—	0	5	2	1	—	—
Total	65	—	10	5	14	37[2]	—	—
Exported roundwood								
Softwoods	599	—	595	0	4	—	—	—
Hardwoods	30	—	0	30	0	—	—	—
Total	629	—	595	30	4	—	—	—
Total supply to domestic mills								
Softwoods	11,380	—	5,395	1,433	3,103	36	868	545
Hardwoods	6,242	—	1,668	102	1,685	1	219	2,568
Total	17,622	—	7,063	1,535	4,788	37	1,087	3,113
Output from primary processing plants								
Lumber								
Softwoods	2,238	—	2,167[3]	72[4]	—	—	—	—
Hardwoods	819	—	819[5]	0	—	—	—	—
Total	3,038	—	2,986	72	—	—	—	—
Plywood and veneer								
Softwoods	677	—	—	677[6]	—	—	—	—
Hardwoods	26	—	—	26[6]	—	—	—	—
Total	703	—	—	703	—	—	—	—
Pulpwood delivered to U.S. mills								
Softwoods	5,408	2,270[8]	NA	NA	3,103	36	NA	—
Hardwoods	2,147	462[9]	NA	NA	1,685	1	NA	—
Total	7,556	2,732	NA	NA	4,788	37	NA	—
Pulpwood chip exports								
Softwoods	150	150	150	—	—	—	—	—
Hardwoods	0	0	0	—	—	—	—	—
Total	150	150	150	—	—	—	—	—
Particleboard and OSB/waferboard								
Softwoods	566[9]	NA	NA	NA	—	—	NA	—
Hardwoods	216	NA	NA	NA	—	—	NA	—
Total	781[10]	NA	NA	NA	—	—	NA	—
Miscellaneous industrial								
Softwoods	618	NA	NA	NA	—	—	NA	—
Hardwoods	125	NA	NA	NA	—	—	NA	—
Total	743	NA	NA	NA	—	—	NA	—
Total particleboard, OSB/waferboard and miscellaneous industrial								
Softwoods	1,183	396[7]	NA	NA	—	—	787	—
Hardwoods	343	151[8]	NA	NA	—	—	190	—
Total	1,524	548	NA	NA	—	—	976	—
Fuelwood								
Softwoods	1,648	1,103[7]	NA	NA	—	—	NA	545
Hardwoods	2,855	287[8]	NA	NA	—	—	NA	2,568
Total	4,503	1,390	NA	NA	—	—	NA	3,113
Total of all products								
Softwoods	11,305	—	NA	NA	3,103	36	NA	545
Hardwoods	6,189	—	NA	NA	1,685	1	NA	2,568
Total	17,494	—	NA	NA	4,788	37	NA	3,113

Table 129.—Continued.

Product	Total	Residue[1] from solid products	Sawlogs	Veneer bolts and logs	Pulpwood, roundwood and whole-tree chips	Pulpwood chip imports	Miscellaneous industrial	Fuelwood
Unused manufacturing residues								
Softwoods	75	75[7]	NA	NA	0	0	NA	—
Hardwoods	54	54[8]	NA	NA	0	0	NA	—
Total	128	128	NA	NA	0	0	NA	—
Total output								
Softwoods	11,380	—	5,395	1,433	3,103	36	868	545
Hardwoods	6,242	—	1,668	102	1,685	1	219	2,568
Total	17,622	—	7,063	1,535	4,788	37	1,087	3,113

NA—Indicates detailed data on residue or roundwood use for this column is not available.

[1]*The residue column shows total residue used in a product which came from sawmills, veneer/plywood mills or miscellaneous industries, except that for particleboard, OSB/waferboard and miscellaneous industrial products this column is total residue from sawmills and veneer/plywood mills only. The sawlog column contains residue from sawmills except for the lumber products row where it contains roundwood contents in lumber. The veneer log column contains residue from veneer/plywood mills except for the plywood/veneer product row where it contains roundwood contents in plywood/veneer. The miscellaneous industrial column contains residue from miscellaneous industrial mills except for the particleboard, OSB/waferboard, and miscellaneous industrial products rows were it contains amounts of roundwood contained in byproducts.*

[2]*Total roundwood and chip imports (630,000) times 79.2 cubic feet per cord.*

[3]*Lumber volume in 1,000 board feet times 64.50 cubic feet per 1,000 board feet.*

[4]*Lumber volume from cores of peeled veneer logs is estimated at 5% of veneer log volume.*

[5]*Lumber volume in 1,000 board feet times 79.47 cubic feet per 1,000 board feet.*

[6]*Plywood/veneer volume in 1,000 square feet 3/8-inch basis times 31.25 cubic feet per 1,000 square feet.*

[7]*Residue use in bone dry tons times (2,000 pounds/27.35 pounds per cubic foot).*

[8]*Residue use in bone dry tons times (2,000 pounds/34.34 pounds per cubic foot).*

[9]*Softwood furnish estimated at 72.4% of total.*

[10]*Volume of particleboard and OSB/waferboard in 1,000 square feet 3/4-inch basis times 62.5 cubic feet per 1,000 square feet.*

Note: Numbers may not add to totals due to rounding.

Sources: Roundwood products from U.S. Forests: Waddell et al. 1989: table 30. Imported and exported sawlogs and veneer logs and pulpwood chip exports: USDA FS 1988e: tables 4–7. Imported and exported roundwood and whole tree chips: USDA FS 1988e: tables 5, 6, and 27. Residues from solid wood products for making pulp products, fuelwood, and other products (particleboard, OSB/waferboard and miscellaneous industrial): Waddell et al. 1989: table 31.

PROSPECTIVE IMPROVEMENTS IN WOOD UTILIZATION TECHNOLOGY

There are at least three techniques and associated rationales to use in preparing forecasts of technological capabilities (Bright 1978): (1) extrapolate trends—assume a steady pace of technological change; (2) project change based on change in technological determinants; and (3) project change based on identifying emerging innovations, their capabilities and possible pace of adoption—assuming a certain pace of adoption for promising innovations. The evaluation method here rests primarily on the third technique and to a lesser degree on the second technique.

Technological innovations will change the competitiveness of wood sources and products by (1) increasing the recovery and decreasing costs for making lumber, panels, paper and paperboard; (2) developing processes/products that expand the use of underutilized species, mill residue and residue left on harvest sites; (3) decreasing the cost of harvesting; (4) increasing the efficiency of end use of wood products; and (5) developing new/improved products and end-use application methods to expand markets for wood. This section identifies many of these technological developments and focuses on projecting costs and/or product recovery for harvesting operations, lumber processing, plywood and nonveneered structural panel processing, and pulp and paper processing. This section also discusses prospective technological changes in construction and manufacturing and the resultant projections of wood product use rates in various end uses.

The next several subsections present an assessment of the effects of technological change in harvesting and processing of softwood lumber/composite lumber, softwood plywood, nonveneered structural panels and paper/paperboard. Each begins with a discussion of possible technological developments in processing. The assessment includes the following steps: (1) identifying likely changes in technology, (2) formulating current and future mill designs which incorporate innovations and have specific recovery and cost characteristics, (3) developing projections of the mix of mill designs used for production through 2040, and (4) calculating recovery and costs resulting from the projected mix of mill designs.

In addition to the assessment of harvesting and softwood lumber, panel and paper/paperboard processing, we present more general assessments of technology change in hardwood lumber processing, wood use in construction, wood use in manufacturing, and wood use for energy. Included in these assessments are an explanation of the technology assumptions used to make the timber consumption and price projections that are shown in Chapter 7.

Harvesting

Timber harvest and transport includes machines and processes whose application varies widely by region, season, terrain, tree species, tree size, stand density, portion of the stand removed, and distance to market. Timber harvesting involves a wide range of equipment tailored to the unique problems posed by each stand. The characteristics of the harvest system used are determined by the major product of each stand (pulpwood, saw logs, veneer logs, tree length logs, whole trees, or chips), stand and species characteristics, expected weather conditions, and the terrain (flat, mountainous, or swamps). Many stands include several product/terrain combinations. To cover the range of conditions encountered, each timber producing region has developed several distinct sets of equipment and procedures. These "solutions" may not necessarily result from a least-cost calculation but from practical adjustments to the highly seasonal and otherwise unpredictable nature of the business, local labor shortages or surpluses, industry purchase policies, and agency/landowner harvest schedules.

In general, for a given harvesting system, costs per unit volume are inversely related to the square of average tree diameter and inversely related to trees per acre. This is because stands are harvested one tree at a time and tree volumes increase with the square of diameter.

Technology Developments

Future timber harvest equipment will closely resemble today's. Tomorrow's logging machines, regardless of improved efficiency, will still have to move over rough surfaces, sever and maneuver heavy trees or logs, and carry them considerable distances in all kinds of weather. Within these constraints, equipment and system designers seek to improve: (1) load capacity, (2) travel and process speed, (3) reliability and longevity, (4) species and product versatility, (5) terrain capability, (6) operator comfort, and (7) safety. Flexibility, rather than maximizing efficiency for a specific kind of stand, is often a more important goal in developing harvest machines and processes.

Table 130 describes specific changes now in development or contemplated for the felling-bunching, skidding-forwarding, processing, loading, and transport functions. These are stimulated by the following problems which current systems do not adequately address:

1. Operating on steep terrain and on sensitive soils;
2. Operating in stands which contain significant portions of unmerchantable species, or multiple products;
3. Operating in low density stands or stands with many small trees;
4. Operating on small tracts required by regulations or fragmented land ownership;
5. Increasingly expensive road construction and long distance hauling; and
6. Improving utilization of branches, tops, bark and previously unmerchantable material.

Other pressures for change include the need to conserve energy and labor and to protect the long-term productivity of forest lands.

There are major opportunities to reduce costs in ground skidding, cable yarding, and log transportation. These functions are the most capital and energy intensive and the most dangerous. Lighter weight machines and engines, improved tires and suspension systems along with much improved fuel efficiency, will reduce costs significantly. As a result of these changes, longer economical skidding or yarding distances will reduce the need for expensive roads.

Current and Projected Harvest System Characteristics

In order to calculate current and projected harvesting and transport cost per thousand board feet for wood harvested in each U.S. region, the production costs were identified for a range of *current* harvesting systems in each region. These systems are shown in table 131 by the key equipment used. Harvest and transport costs for each system are affected by average tree diameter and volume per acre.

Each harvest system was developed to be close to the "optimum" for the typical diameter/volume/terrain conditions encountered in that region and typical conditions in one region may be extreme conditions in another. Generally, the regional ranking from lowest cost per unit volume to highest is as follows: South, Pacific Northwest-East, Pacific Southwest, Pacific Northwest-West and Rocky Mountains (table 81).

Projected Mix of Harvesting Systems

Substantial shifts in system mix are expected in various regions (table 131). On the flat terrain in the East, and in the North and South, loggers will rely increasingly on mechanized feller-bunching and grapple skidding to central landings for processing and loading. Chainsaw felling is generally being replaced by feller-bunchers in pulpwood operations but will continue to be widely used on saw log and veneer operations to protect valuable butt logs. It is difficult, however, to attract workers to do this hard, dangerous chainsaw work. Grapple skidders are expected to replace most cable skidders by 2040 for safety reasons. Grapple skidders will increase their share of production from 43% to 63% in the South and 5% to 24% in the North. In the South, use of the unique and very labor intensive bobtail truck and farm tractor systems are expected to decline, but will still produce about one-eighth of roundwood output in the South by 2040. These labor intensive systems persist, despite the availability of more efficient equipment, because of a traditional need for off-season farm employment. These systems often produce the least expensive wood, primarily due to the lack of employment alterna-

Table 130.—Technology developments in timber harvesting.

Process	Description	Impact
Felling and bunching		
Lighter weight and/or lower ground pressure machines	For flat terrain, feller-bunchers either smaller, mounted on lighter chassis, or equipped with larger tires, high speed tracks, or air cushions.	Less soil erosion or compaction, maintains productivity, enables harvests on previously "unsuitable" land; fewer roads required.
Walking or self-leveling feller-bunchers or felling-directors	Feller-bunchers able to negotiate slopes over 50%. In larger diameter western stands, more portable machines that direct felling with hydraulic jacks.	Less soil erosion or compaction, maintains productivity, enables harvests on previously "unsuitable" land; fewer roads required.
Multistem carriers attached to feller-bunchers	For smaller diameter stands and plantations, the ability to accumulate several stems before dropping.	Will make plantation management and pole timber thinning economic.
Saw felling heads	In lieu of shears, saw heads eliminate butt splitting.	Improves lumber and veneer recovery from butt log.
Skidding and yarding		
For ground-based skidding and forwarding:		
Lighter weight and/or lower ground pressure machines	Skidders and forwarders, either smaller or mounted on lighter chassis, or equipped with larger tires, high speed tracks, or air cushions.	Less soil erosion or soil compaction, therefore maintaining productivity or enabling harvests on previously "unsuitable" land: fewer roads required.
For aerial cable yarding systems:		
Grapple yarders	Cable yarders that can bunch and grapple by remote control.	Reduces crew size, inefficiency, and danger in hand choker setting
Self releasing chokers or grapples	Load can be released automatically at landing.	Reduces crew size, inefficiency, and danger with hand choker setting.
Synthetic ropes and rigging	Replaces expensive heavy wire cable and massive steel running gear.	Reduces equipment cost, more usable load.
Remote log and tree weight estimation	Enables yarder operator (with or without computer assistance) to judge tree or log weight and thereby plan each load.	Improves system production, safety, and reduces equipment breakage.
Cable tension monitors	Enables yarder to electronically monitor load during retrieval.	Improves system production, safety, and reduces equipment breakage.
More mobile tail block systems	Depending on slope, cable yarding systems require ends of cable system to be moved frequently.	Reduces crew requirements, and increases production.
Cheaper more reliable anchors	Previously, very large stumps were used for cable anchors but these are now seldom available.	Will enable harvests on small timber in steep terrain, extending the area of "suitable" lands.
Smaller systems for smaller timber primarily in the east	Cable yarders for western U.S. conditions are for large logs and long steep slopes. Eastern mountains are less demanding but need cable yarding to avoid soil erosion and residual stand damage caused by partial harvests.	Extends the area of "suitable" land in the east. Reduces need for expensive road construction.

Table 130.—Continued.

Process	Description	Impact
Processing		
Mechanized delimbers	Hardwood sawlogs are expensive and dangerous to delimb. Softwood log form is better and delimbing is less of a problem.	Reduces labor requirements, improves production and safety.
Debarkers	Removing bark on the landing before chipping or hauling.	Reduces hauling cost, increases utilization if clean chips can be produced, leaves more nutrients on site.
Smaller, lighter chippers and/or chunkers	Chips or chunks offer the opportunity to recover vast amounts of wood previously wasted. Chunks are very large chips which require less energy to produce.	Improves utilization, extends timber supply, removes unwanted stocking hindering regeneration.
Merchandisers	Combined chipping/chunking and roundwood processor in the woods that produce and direct species and tree components to their highest value use.	Maximizes return to landowners, extending area of "suitable" lands.
Transportation		
Log weight estimation	Knowing log weights beforehand can increase average load size without overloading.	Reduces overload fines, equipment breakage, improves safety.
Automatic truck weighing	Sensors installed on each truck reporting actual weight.	Reduces overload fines, equipment breakage, improves safety.
Central tire inflation	Compressor and piping on each truck could inflate or deflate tires. Dirt roads last longer when tires have low pressure but highways require high pressure for high speeds.	Extends forest road life.
General developments		
Lightweight machine construction	Development of metal alloys, ceramics, plastic composites for chassis, engine and components will alter machine design, construction and performance.	Lower fuel cost, more power available for useful work, machines can range farther, reducing road requirements, less soil compaction and/or erosion.
Improved fuel economy	New engine designs such as fuel efficient 2-cycle engines, air cooled diesels, gas turbines, and fluidics will decrease fuel consumption and the way power is transmitted for traction or processing.	Lower fuel cost, more power available for useful work.
Improved engine, chassis, suspension, and maintenance	Computer monitoring of machine loading and maintenance needs will increase machine life.	Lower fixed machine costs per unit volume. Lifetime maintenance costs may exceed purchase price.
Ergonomic design (human factor engineering)	Designing machines and their controls to suit the tolerances of humans is a largely untouched but crucial area in harvest equipment design.	Increased production and reduced accidents. Decreased cost for workman's compensation insurance.
Computer aided systems analysis and operation	On-board computer, as well as off-machine systems analysis and operations research technique can make market sensitive real-time decisions and train employees.	Increased productivity, reduced wood losses or grade reduction, more rapid training.

Table 131.—Proportion of timber harvested by various systems by region in 1985, with projections to 2040.

Section and region	1985	Projections 2000	2010	2020	2030	2040
				Percent		
South—flat terrain						
Roundwood						
Cable skidders	35.0	30.0	25.0	20.0	15.0	10.0
Grapple skidders	43.0	47.0	51.0	55.0	59.0	63.0
Bobtail trucks and farm tractors	17.0	16.0	15.0	14.0	13.0	12.0
Whole tree chippers	5.0	7.0	9.0	11.0	13.0	15.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
North[1]—flat terrain						
Roundwood						
Cable skidders	61.0	50.0	40.0	31.0	22.0	14.0
Grapple skidders	26.0	29.0	33.0	36.0	39.0	41.0
Forwarders	5.0	9.0	13.0	17.0	20.0	24.0
Whole tree chippers	9.0	11.0	14.0	16.0	19.0	21.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
North[1] and South—steep terrain						
Cable yarders	10.0	16.0	22.0	28.0	34.0	40.0
Skidders and forwarders	90.0	84.0	78.0	72.0	66.0	60.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Rocky Mountains[2]						
Tractors—jammers	86.1	83.9	81.7	79.5	77.2	75.0
Cable yarders	13.9	16.1	18.3	20.5	22.8	25.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Pacific Coast						
Pacific Southwest[3]						
Highlead	6.4	6.1	5.8	5.6	5.3	5.0
Skyline—short	23.2	24.0	24.8	25.4	26.2	27.0
—medium	7.4	8.3	9.2	10.2	11.1	12.0
—long	0.0	0.2	0.4	0.6	0.8	1.0
Tractors	63.0	61.4	59.8	58.2	56.6	55.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Pacific Northwest						
Pacific Northwest-West						
Highlead	20.0	18.0	16.0	14.0	12.0	10.0
Skyline—short	37.5	38.0	38.5	39.0	39.5	40.0
—medium	7.5	8.0	8.5	9.0	9.5	10.0
—long	2.5	2.6	2.7	2.8	2.9	3.0
Tractors	32.5	33.4	34.3	35.2	36.1	37.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Pacific Northwest-East						
Highlead	3.0	3.4	3.8	4.2	4.6	5.0
Skyline—short	12.0	12.6	13.2	13.8	14.4	15.0
—medium	6.0	6.4	6.8	7.2	7.6	8.0
—long	0.0	0.4	0.8	1.2	1.6	2.0
Tractors	79.0	77.2	75.4	73.6	71.8	70.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1]*Includes North Dakota, Nebraska, and Kansas.*
[2]*Excludes North Dakota, Nebraska, and Kansas.*
[3]*Excludes Hawaii.*

tives. In the North, forwarders are expected to expand from about 26% to 41% by 2040 and whole tree chipping is expected to increase from 9% to 21% by 2040.

The East also possesses considerable "mountainous" terrain. About 55%, 6%, 13%, and 11% of the Northeast, North Central, Southeast, and South Central regions, respectively, are considered mountainous. While not as rugged as the Rockies or Pacific Coast, the proximity of a large concerned population, very erodible soils, and generally less productive sites, heighten the need for cost-effective and environmentally sound harvesting equipment and methods. To date, several small scale cable yarding systems adapted from European and West Coast equipment have been applied with some success. We assume cable systems could increase from 10% of the harvest from mountainous terrain to 40% between 1985 and 2040.

On the Pacific Coast the rugged terrain and extremely large trees frequently require expensive and complex cable yarding systems. Despite their cost, these systems are effective in reducing soil erosion. Highlead systems are expected to decline and to be replaced by more versatile skyline systems. Both use portable guyed steel towers but skyline running gear is more complex. Almost all trees are hand felled in the West because of large diameters and steep slopes. Ground skidding using rubber-tired or crawler tractors on less steep slopes is expected to remain about the same in all Pacific regions. Tractors now account for 33%, 79%, and 63% of production in the Pacific Northwest-West, Pacific Northwest-East, and Pacific Southwest subregions, respectively.

In the Rockies, movable skyline systems are widely used but are expected to be replaced somewhat by smaller cable yarders adapted from the Pacific regions.

Generally, shifts in system mix in all regions are expected to be from less efficient to more efficient systems, and from more labor intensive to less labor intensive systems.

Projecting Harvesting Costs as Stand Characteristics and System Mix Change

Four factors were used to make initial harvest cost projections in each region to 2040: (1) the harvest and transport costs for systems used in each region, (2) the proportion of wood harvested with each system (table 131), (3) the average tree diameter and volume per acre, and (4) the assumed rate of productivity improvement for each harvesting system. The initial harvest cost projections were further modified as noted below.

Tables of harvesting costs (for a range of tree diameters and stand volumes) were computed for each region and decade by weighing harvest cost for individual systems by the proportion of wood harvested by that system (table 131). A single average cost was selected from these tables using projected tree diameter and volume per acre for that region and decade.[45] These projections assume that productivity of individual harvesting systems will not increase between 1985 to 2040. They also assume constant wage rates and energy prices. The initial projected harvest costs change only as a result of changes in stand characteristics and system mix (Bradley 1989). The initial projections were modified in certain regions.[46]

[45] *Tree diameter (DBH) and stand volume per acre were projected to change as follows between 1985 and 2040:*

	DBH	Vol/A
North	+2%	+45%
South	−7%	+31%
RM	−27%	+26%
PNW-W	−49%	0%
PNW-E	−27%	0%
PSW	−49%	0%

[46] *For the Rocky Mountain region, initial logging cost growth rates were raised to equal those of the Pacific Northwest-East. This retains the past position of the Rocky Mountains as the highest cost western U.S. region. Environmental limitations on logging are likely to remain at least as stringent in the Rocky Mountains as elsewhere in the West, thus maintaining higher costs. For the South, logging cost growth rates were raised to maintain the current relative regional cost structure—the revised growth rate for the South, overall, is slightly greater than for the Rocky Mountains and Pacific Northwest-East. Higher cost growth rates in the South could result in part from more rapidly rising labor costs than in other regions (Adams 1989).*

Based on these assumptions and methods, logging costs are projected to increase at a slower rate than that experienced from 1952 to 1985 in all regions except the South. The rate of increase between 1985 and 2040 is greatest in the South—57% (table 81). The slowest growth is 49% in the Pacific Southwest.

Softwood Lumber and Composite Lumber Processing

Conventional softwood lumber is made by breaking down logs, while composite lumber is made by recombining wood flakes and/or veneer into products which perform like lumber in selected applications. Softwood lumber is made from many species for use in construction and remanufacture. It is made in length multiples of 1 or 2 feet as specified by various grading rules. Width commonly varies from 2 to 16 inches nominal (actual width is less). Lumber is categorized by thickness: boards—less than 2 inches nominal; dimension—2 to just less than 5 inches nominal; and timbers—5 inches or more nominal. Lumber for making products is graded under the American Lumber Standard. Lumber for construction may be stress-graded, nonstress-graded, or appearance-graded. Lumber for remanufacture may be factory (shop) grades; industrial clears; molding, ladder, pole timber, or pencil stock; or structural laminations (USDA FS 1987b).

Conventional lumber processing includes yard handling of logs, bucking, debarking, log breakdown by primary and secondary sawing, planing, drying, grading and preparation for shipping. Timber characteristics that influence the recovery of lumber from roundwood and the processing costs include log diameter, length, shape, and defects. Timber characteristics have less influence on the rate of recovery of composite lumber from roundwood. Hardwood lumber processing is discussed in a later section.

Technology Developments

The softwood lumber industry adopts technological improvements to produce lumber in order to (1) reduce costs of wood, (2) reduce processing costs, and (3) maintain and enhance quality for evolving end uses—all while facing a timber resource that is declining in size and quality. Many improvements seek to reduce wood costs and processing costs in response to competition from lumber imports, decline in timber diameter, lower cost for hardwoods compared to softwoods, and the small but growing proportion of plantation timber which has a higher proportion of juvenile wood. Other technological developments seek to minimize processing costs by reducing the need for costly capital, labor, and energy.

Two general trends in sawmill technology are expected. First, more sawmills will be part of integrated wood processing systems rather than independent profit centers. These systems may include logging, wood merchandising, sawmills, plywood mills, particleboard mills, pulpmills, and wood use for energy. These integrated wood processing systems will work to allocate each tree stem to its most profitable use. Second, equipment within a sawmill will continue to change from a collection of independent machines connected by a material transport system to an electronically integrated collection of machines linked by conveyors. For production of traditional lumber products, techniques that increase wood recovery and thus reduce cost include improved scanning to measure log shape; computer control for optimal log breakdown based on the best-opening-face (BOF) concept to provide improved bucking, primary and secondary breakdown, edging and trimming; thinner saw blades, longer wearing teeth and better saw guides to reduce saw kerf and sawing variation; and more closely controlled drying using improved moisture sensing and removal to reduce energy use and degrade (table 132).

Although we do not evaluate their potential impact here, several new lumber type products can further increase wood recovery. These include laminated veneer lumber, composite lumber, composite wood I-beams and hardwood structural lumber made by the Saw-Dry-Rip

Table 132.—Technological developments in softwood lumber, hardwood structural lumber and composite lumber processing.

Product type and development	Description	Impact
Softwood lumber		
Log and board scanners linked with process optimizers	Improved scanning of log and board shape coupled with increasingly sophisticated computer software and log/board positioning equipment provide improved log bucking, primary breakdown, secondary breakdown, edging and trimming	Improves recovery of lumber
Sawline loss reduction	Kerf can be reduced with thinner saws and sawing variation can be reduced with developments of low expansivity alloys for saw blades, improved saw guides and lower wearing narrower saw teeth.	Improves recovery of lumber
Abrasive planing	Abrasive planing, which removes much less wood than knife planing, can be used more as surface irregularities decrease with use of more stable saws.	Improves recovery of lumber
Improved control of drying	Sensing of temperature drop across the load in all zones of a dryer decreases degrade of pieces.	Holds down cost of drying, improves lumber recovery
Tomography for log defect detection	Experiments indicate computer aided tomography using x-rays can recognize internal log defects which could supply computer programs with information to improve grade recovery of lumber.	Improves recovery of lumber
Hardwood lumber—structural		
Saw-dry-rip processing[1] for hardwood structural lumber	The saw-dry-rip-sequence for processing warp prone medium density hardwoods sharply increases the yield of STUD grade structural hardwood lumber.	Production of structural lumber from plentiful medium density hardwoods
Composite lumber		
Laminated veneer[1] lumber	Wide dimension lumber made from laminated sheets of veneer efficiently uses smaller diameter logs to replace long length larger structural lumber (2 by 8, 10, 12) made from larger diameter logs.	High recovery from smaller logs to make deep dimension structural lumber
Parallel strand[1] lumber	Long strands of veneer residue are used to make deep long structural lumber.	Recovery of veneer residue to make structural lumber
Com-ply lumber[1]	Com-ply lumber is formed of a flakeboard center with several laminations of veneer at the edges. Hardwood and softwood may both be used with high recovery from smaller logs to make structural lumber for housing.	High recovery and joint use of smaller diameter softwoods and hardwood to make lumber

[1] *The effects of potential expanded use of these processes is not included in the technology projection model or the timber supply/demand projections.*

(SDR) process. Laminated veneer lumber has gained acceptance where uniform strength, greater depth and long-span support is needed. Composite wood I-beams with laminated flanges (top and bottom edges) and plywood or flake board webs (centers) have also gained acceptance where long-span support is needed. Composite lumber for construction has been produced in the form of Com-ply (lumber with a core made from hardwood and softwood flakes and edges made from veneer) but the prospects for its wide use are not clear. Although there has been little commercial application, structural lumber may be made from medium density hardwoods, such as yellow poplar and cottonwood, using SDR (Maeglin et al. 1981, Maeglin 1985, Allison et al. 1987). The SDR process reduces the tendency of these same species to warp due to growth stresses and it can also be used to reduce warping in lumber made from logs with a high proportion of juvenile wood.

Current and Projected Characteristics of Lumber Processing

A range of sawmill designs that include many of the innovations noted in the previous sections were prepared as part of calculating future lumber recovery factors (LRF) and lumber processing costs (Williston 1987). Mill designs for laminated veneer lumber, composite wood I-beams, composite lumber, or SDR lumber processing were not included. Some designs that were used include considerable improvement over traditional sawmills, including reduction in kerfs and dressing allowance, closer approach to theoretical highest yield (table 133), an increase in log throughput rate and a decrease in labor requirements.

For five regions, mill designs for three mill types at four technology levels were prepared. Mill types were (1) stud mills, (2) random length dimension mills, and (3) board mills. Technology levels were (1) current average mill producing less than 5 million board feet per year, (2) current average mill producing more than 5 million board feet per year, (3) mid-1980s best mill, and (4) future mill.

The chief features of current average mills producing less than 5 million board feet per year were use of a carriage to transport logs with circular saw breakdown, kerf in excess of .250 inch, little or no computer control of breakdown, air drying of lumber and knife planing. The remaining types of mills all produce more than 5 million board feet per year and use kilns for drying lumber.

The current average mills producing more than 5 million board feet per year vary by product produced. The stud mill uses canter log transport and a quad band headrig, kerf less than .200 inch, computer controlled breakdown, but no optimizing edger or trimmer. The random length dimension mill uses full taper canter log transport and a quad band headrig, kerf less than .200 inch, and computer controlled breakdown and edging. The board mill uses carriage log transport with a single band headrig, kerf of about .250 inch, computer assisted log offsets, and an edger optimizer.

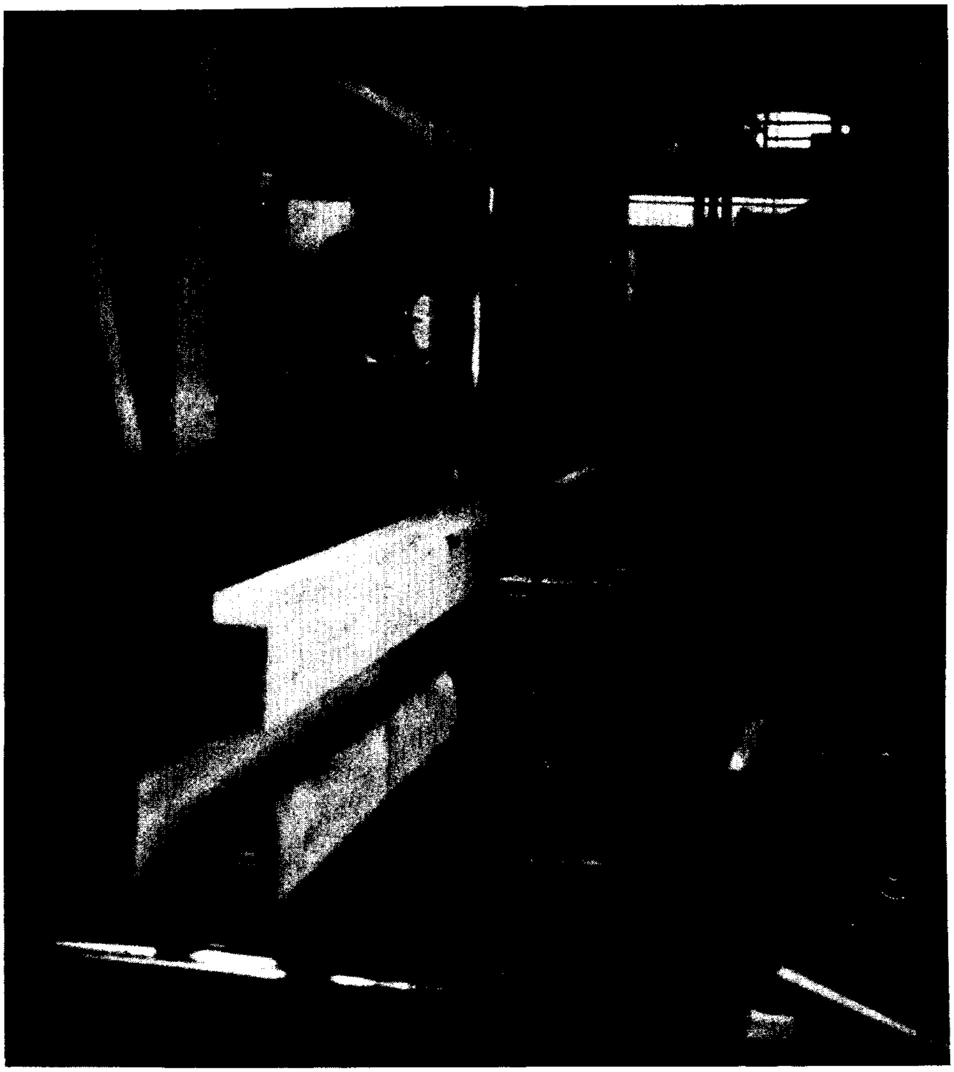
Table 133.—Current and projected designs of softwood sawmill systems.

Age of technology[1], size of mill and type of mill	Log transport system/ headrig type	Sawing parameters: Kerf: Headsaw	Kerf: Resaw	Dressing allowance	Percent[2] of BOF yield attained
				Inches	
Current less than 5 MMBF					
Stud	Carriage/Circular saw	.284	.284	.119	72
Random length dimension	Carriage/Circular saw	.284	.284	.119	72
Board	Carriage/Circular saw	.284	.284	.118	72
Current more than 5 MMBF					
Stud	Canter/Quad band—ex. North	.202	.173	.119	72
	Carriage/Circular saw—North	.205	.179	.119	72
Random length dimension	Full taper canter/Quad band — except North	.202	.173	.119	72
	Carriage/Circular saw—North	.205	.179	.119	72
Board	Carriage/Single band	.252	.183	.118	72
Mid-1980s best					
Stud	Overhead end dog/Quad band	.121	.119	.107	74
Random length dimension	Side dog sharp chain/Quad band	.121	.119	.107	74
Board	Overhead end dog/Quad band	.121	.119	.107	74
Future					
Stud	Magazine/Precision canter	.110	.100	.015	76
Random length dimension	Integral/Precision canter	.110	.100	.015	76
Board	Overhead end dog/Quad band	.110	.100	.015	76

[1]*Mid-1980's best technology and future systems are mills producing more than 5 million board feet per year.*

[2]*Percent of theoretical lumber recovery attained, where theoretical recovery is computed using the Best-Opening-Face computer program with sawing parameters shown in the table.*

Source: Headrig type: Williston 1987. Kerfs and Dressing allowance: Steele et. al. 1987, Steele et al. 1988a. Estimates for mid 1980s best and future mills are from Lunstrum and Danielson 1987.



This double-bandsaw headrig with an end-dogging carriage is one example of innovative technology used in western sawmills.

The mid 1980s best mills also vary by product. All are assumed to have headsaw and resaw kerf just over .125 inch. The stud mill uses overhead end dog log transport and a quad band headrig, computer controlled breakdown, and an optimizing edger. The random length dimension mill uses side clamp sharp chain log transport with a quad band headrig, computer controlled breakdown, and an optimizing edger. The board mill uses overhead end dog log transport with two reducer heads and a quad band headrig, computer assisted log offsets, and an edger optimizer.

The future sawmills are assumed to come into use in the mid 1990s. In the future stud mill, long logs are scanned, bucked and sorted by diameter, length and shape. Input may include plywood cores. Logs are sorted by diameter and irregularities removed to permit high speed magazine feed (30 logs/minute). Logs are cut by precision machinery canters with offset capability which produce smooth 2x4's from the sides and 2x6's from the cant. Stacking is done by an automatic crib-stacker. Lumber is dried under restraint at high temperature and high speed. Dressing removes .015 inch by touch sanding. Grading is done by noncontact scanning at 650 feet per minute followed by sorting and packaging.

In the future random length dimension mill, long logs are scanned and bucked for optimum length and shape. Logs are sorted by diameter, length and grade before storage in the log yard. Log infeed is by diameter class permitting infeed at 8.5 logs/minute. Log transport is by flat chain feed with side and top rollers for positioning. The headrig has log offset and taper sawing capability and contains four reducer heads, a gang saw and built-in edgers. Stacking is automatic. Lumber is dried at high temperature. Dressing removes .015 inch by touch sanding. Grading is done by noncontact scanning followed by sorting and packaging.

In the future board mill, logs are sorted into two grade categories and several diameter classes. Computer aided tomography type scanning is used to sense interior defects. Logs are fed into the mill by class in relatively long runs at 3.5 logs per minute per headrig. Coded grade marks on logs indicate the position of sweep and crook, the location of clear and common faces, and the depth of cut to maximize value recovery. Smaller diameter logs with only one or two opposing clear faces go to a side with overhead end dog transport and a reducer quad band headrig. Larger diameter logs with two or more clear faces go to a side with overhead carriage transport and 90° turning capability and a reducer quad band headrig. Common lumber cants go through an optimizing gang saw. Upper grades pass through an optimizing edger that scans and cuts to optimize value based on appearance grade. A computer controls drying to 12% moisture content. Dressing removes .015 inch by abrasive planing. Boards are then scanned for appearance grade and trimmed and sorted automatically.

Projected Mix of Lumber Processing Systems

Average LRF and processing costs were computed for each region by taking a production-weighted average over all mill types and technology types (table 134). The averages change over time as the proportion of production moves from current technology to the best technology of the mid-1980s to future technology and as average log diameter declines (table 135).[47]

New sawmill capacity is introduced in two ways: remodeling or new construction.[48] Between 1982 and 2040, new or remodeled capacity that is small mill technology[49] is assumed to decline nationwide from 16% to 8%. In 1982 the percentage of mill capacity using this small mill technology varied from 21% in the South to 0.1% in the Pacific Southwest (McKeever 1987b). Between 1982 and 1990, the large mill technology will initially be replaced by current average technology for mills greater than 5 million board feet per year, but will gradually change so that by 1995 large mills will be replaced only by mid-1980s best technology. Between 1995 and 2040, the proportion of new or remodeled capacity that is mid-1980s best technology will gradually decline to zero, while the proportion with the future technology will increase (table 134).

[47]A computer model was used to compute lumber recovery factor (LRF) and processing costs for 3 mill types at each of 4 technology levels for 6 regions. Many mills have the same basic design across regions. Each design has (1) a basic equipment layout; (2) estimated costs for equipment, maintenance, labor, energy, and administration; (3) estimated log throughput rate by log diameter (Williston 1987); and (4) an equation to estimate LRF by log diameter that was prepared using best-opening-face (BOF) computer software (Lewis 1985). Associated with each design and LRF equation are specific sawing characteristics, such as split-taper or full-taper sawing, headsaw kerf, resaw kerf, dressing allowance (table 133), trimming procedures, and proportion of theoretical yield obtained. Sawing parameters for "current average" technologies are from the Sawmill Improvement Program (SIP) (Steele et al. 1987, Steele et al. 1988a) and estimates by Lunstrum and Danielson (1987). Sawing parameters for "mid-1980s best" and "future" mills were estimated by Lunstrum and Danielson (1987). Proportion of theoretical yield attained was estimated by reducing BOF estimated LRF's to match estimated 1985 "real world" recoveries in the Timber Assessment Market Model data set (Haynes 1987). LRF and costs were calculated for each mill type/technology level in each region for the average log diameter processed (table 135). Processing costs exclude wood cost and revenue from sale of mill residue. For our projections to 2040, it is assumed that real wage and energy costs are held constant at 1986 levels. The model's first year is 1982. Log diameters for 1982 are from SIP data (Steele et al. 1988b). The initial proportion of lumber made in mills producing less than 5 MMBF per year is from state and national mill directories (McKeever 1987). The proportion of capacity in stud mills (10%), random length dimension mills (65%) and board mills (25%) is based on data from the USDC Bureau of Census (1982).

[48]A mill is assumed to be remodeled or shut down after 10 years. In 1982, capacity is assumed to be uniformly distributed among 10 1-year age classes. Beginning in 1983, a mill in the 10-year-old age class is assumed to be remodeled or shut down. The mill is assumed to be shut down if there is an externally specified decrease in total capacity. Entirely new capacity is added to fulfill a need for an increase in total capacity.

[49]Current average technology producing less than 5 MMBF.

Projected Recovery and Costs as Log Diameter and Mix of Systems Change

Average softwood lumber recovery in the United States is currently about 49% of the cubic volume processed, and the lumber recovery factor (LRF) is 6.8 board feet lumber tally per cubic foot log scale. Overall recovery is projected to improve by 15% between 1985 and 2040, to 57%. Projections of LRF average 7.8 by 2040 and exceed more than 8.4 in the Pacific Northwest-West (table 88). These projections reflect a decline in diameter of logs processed (table 135). The national averages are weighted by regional production and are influenced by the regional production shift from the West to the South.

Projected increases in lumber recovery vary by region. Between 1985 and 2040, recovery will increase by 19% to 24% in the South and Pacific Northwest-East regions (table 88) where decreases in log diameter are limited. Recovery improvement will be least in the Pacific Northwest-West (8%) and Pacific Southwest (11%) due to a projected 24% decline in average log diameter. The wide range in regional recoveries in 1985 (6.02 to 7.87) will narrow by 2040 (7.18 to 8.47). The Pacific Northwest-West and the Pacific Southwest will retain the highest recovery factors because the South is projected to retain a significant number of small, less efficient mills.

Softwood lumber processing costs are projected to decrease in all regions by 2040 (table 82). Processing costs exclude wood costs and revenue from sale of residue. This departure from the upward cost trend in the 1970s is attributable to continued improvements in sawing technology; less capital, labor and energy per unit; and projected constant wage rates and energy prices. The cost decline between 1985 and 2040 will be the greatest in Pacific Northwest-East (24%), lowest in the Pacific Southwest and Rocky Mountains (16–21%), and 22% in the South and Pacific Northwest-West. Newer mills will be able to keep costs per unit output down, even in regions where diameters decline, by increasing their log throughput rate.

The Impact of Technology Change on Lumber Manufacturing Costs

Lumber manufacturing costs include costs for stumpage, harvesting and hauling, and processing. The technology changes discussed previously hold down the cost

Table 134.—Proportion of various softwood sawmill systems by region in 1985, with projections to 2040.

Section and region	1985	Projections 2000	2010	2020	2030	2040
		Percentage of production				
North[1]						
Old less than 5 MMBF	61	54	49	43	38	33
Old more than 5 MMBF	37	3	0	0	0	0
Mid-1980s best	2	41	39	31	20	7
Future	0	2	12	26	42	61
South						
Old less than 5 MMBF	21	19	17	15	13	11
Old more than 5 MMBF	75	6	0	0	0	0
Mid-1980s best	4	73	64	46	28	9
Future	0	3	20	39	59	80
Rocky Mountains[2]						
Old less than 5 MMBF	12	11	10	9	7	6
Old more than 5 MMBF	84	7	0	0	0	0
Mid-1980s best	4	80	69	50	30	9
Future	0	3	21	42	63	84
Pacific Coast						
Pacific Southwest[3]						
Old less than 5 MMBF	0	0	0	0	0	0
Old more than 5 MMBF	95	8	0	0	0	0
Mid-1980s best	5	89	77	54	32	10
Future	0	3	23	46	68	90
Pacific Northwest						
Old less than 5 MMBF	1	1	1	1	1	0
Old more than 5 MMBF	94	8	0	0	0	0
Mid-1980s best	5	88	76	54	32	10
Future	0	3	23	45	67	90

[1]*Includes North Dakota, Nebraska, and Kansas.*
[2]*Excludes North Dakota, Nebraska, and Kansas.*
[3]*Excludes Hawaii.*

Table 135.—Trend in diameter of softwood logs processed by sawmills, by region, 1985, with projections to 2040.

Section and region	1985	Projections 2000	2010	2020	2030	2040
		Inches				
North[1]	10.1	10.1	10.1	10.1	10.2	10.2
South	10.3	10.3	10.1	10.0	9.9	9.8
Rocky Mountains[2]	10.6	10.2	9.8	9.6	9.4	9.2
Pacific Coast						
Pacific Southwest[3]	13.6	12.4	11.9	11.4	11.0	10.4
Pacific Northwest						
Pacific Northwest-West	12.5	11.4	11.0	10.5	10.1	9.6
Pacific Northwest-East	10.6	10.2	9.8	9.6	9.4	9.2

[1]*Includes North Dakota, Nebraska, and Kansas.*
[2]*Excludes North Dakota, Nebraska, and Kansas.*
[3]*Excludes Hawaii.*
Source: Estimates for 1985 are based on data from the Sawmill Improvement Program, see Steele et al. 1988b.

of making lumber by decreasing the delivered cost of logs per unit of lumber output and by holding down sawmill processing costs.

Projected improvements in lumber recovery will hold down the cost of logs as a component of lumber costs. Even though delivered log costs for the Pacific Northwest-West and South are projected to increase by 10.2% and 13.0%, respectively, per decade through 2040, the cost per unit of lumber output increases only 9.9% and 10.0% per decade, respectively (fig. 78). Technological change is projected to be more effective in holding down log costs as a component of lumber costs in the South due to smaller projected declines in log diameters.

Other improvements in lumber processing, in addition to LRF improvement, will also shield the cost of making lumber from projected increases in log costs. Even though delivered log costs for the Pacific Northwest-West and South increase by 10.2% and 13.0% per decade through 2040, total lumber manufacturing costs increase only 4.9% and 5% per decade on average (fig. 79). Most of the projected increase occurs by 2010 to 2020. Technological change is more effective in holding down overall lumber manufacturing costs in the South. As a result, the South is projected to widen its comparative advantage in lumber manufacturing costs relative to the Pacific Northwest-West over the projection period (fig. 79).

Hardwood Lumber Processing

The principle use of hardwood lumber is for remanufacture into furniture, cabinet work and pallets,

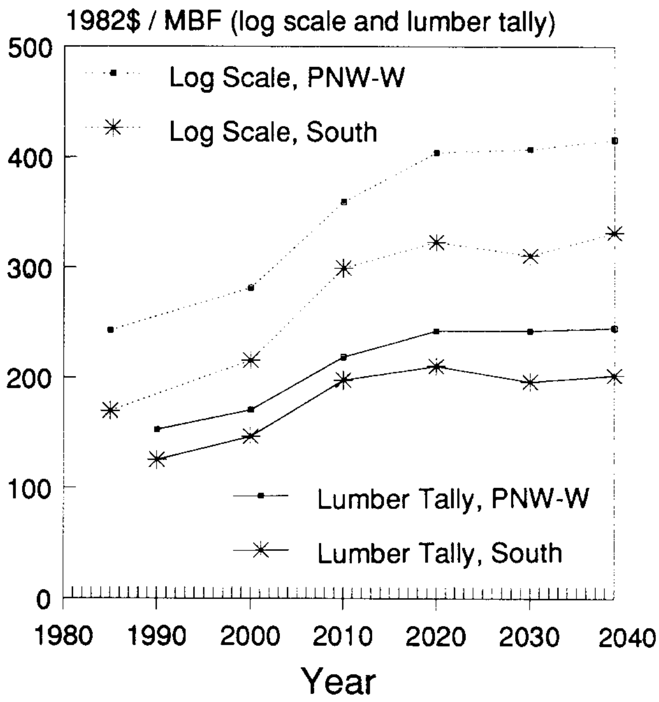


Figure 78.—Delivered log cost for softwood lumber, PNW-West and South.

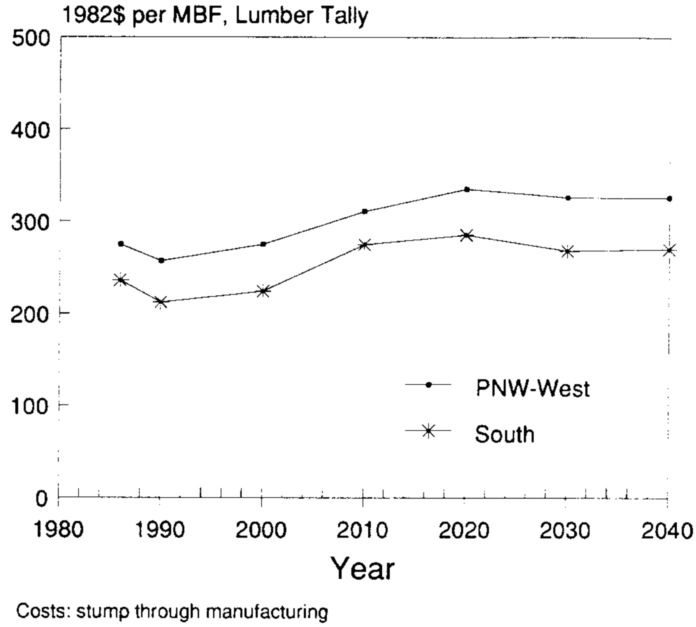


Figure 79.—Total softwood lumber-making costs, PNW-West and South.

or directly into flooring, paneling, molding and millwork. It is mainly graded and sold as factory lumber, or processed into dimension parts and finished products. Factory lumber comes in random widths and is graded by the number and size of clear cuttings that may be obtained. It is intended to be cut into smaller pieces after kiln drying (dimension parts) that will be used to make furniture or other fabricated products. Pallet parts are cut from green lumber or cants. Dimension parts are normally kiln dried parts with specific thicknesses, lengths and widths. They may be sold rough or surfaced, and semi-fabricated or fabricated for further use in making products such as furniture. Finished products are sold in finished form. The highest volume example is flooring. Others include lath, siding, ties, planks, car stock, construction boards, timbers, trim, molding, stair treads and risers.

The production of hardwood lumber in general is less automated and less sophisticated than softwood lumber processing. A majority of the mills have wide-kerf circular headrigs instead of narrow-kerf band headrigs and the production capacities are much smaller in hardwood mills. Sophisticated log scanning, computer assisted log processing, and computer controlled edging and trimming are technologies developed for softwood sawmills and are seldom used in the hardwood industry. In general, the technology is too expensive for most options or does not apply to the production of hardwood lumber. Most hardwood logs are processed to produce the highest appearance grade lumber possible. Processing for higher grade lumber normally stops when low grade faces appear on the remaining center cants. Cants are subsequently processed for lower grade lumber or pallet parts at the same mill or a pallet plant.

In general, top grade first-and-second and select (FAS & Sel) lumber is used for moldings, millwork, export, and other uses that require clear or almost clear lumber.

In this cabinet parts rough mill, lumber is ripped into strips (far left) after an operator marks edges to be trimmed with two laser lines, and a computer determines the size of strips to fill mill needs. (Credit: Phil Araman, USDA Forest Service)

Secondary quality lumber, graded number 1 common (1C) and number 2 common (2C), is used primarily for wood furniture, upholstered furniture, cabinets, flooring, and other products that do not require clear lumber. Material below 2C grade is used in railroad ties, mine timbers, pallets, and flooring.

Hardwood lumber drying is more critical than softwood drying for two reasons. First, hardwood lumber must be dried down to 6-8% moisture content for furniture instead of the 15% moisture for most softwood lumber that is kiln dried and used in construction. Second, hardwood lumber must be dried more slowly to avoid drying degrade such as splits, checks, warping, staining, and internal honeycombing. These defects reduce the value and usefulness of the lumber.

After drying, hardwood lumber is converted into cuttings for furniture, cabinets, moldings, flooring, stair treads and risers, and other product parts in processing facilities called rough mills. The lumber is planed, crosscut and ripped, or ripped and crosscut into parts or cuttings. Many of the cuttings are edge glued, planed and then re-ripped to parts. In some systems finger jointing is used to make long parts out of short cuttings. In the future, we may see more rough mill type processing tied directly to sawmill and drying operations. For secondary quality lumber (1C and 2C) we could see production of green dimension cuttings followed by drying. With this system, dry kilns would not have to dry all the waste lumber that is discarded when lumber is cut into dimension parts. This system would increase the capacity of existing kilns to produce dry dimension parts.

Possible Changes in Hardwood Lumber Production

The main pressures to improve or change hardwood lumber processing techniques stem from the need to manufacture enough better grade material for important export and domestic markets. Processors need to improve yields, but they must improve quality and contain costs to maintain markets and reduce the potential competition from substitute wood or nonwood products. Modernization with computer aided manufacturing and computer controlled processing are keys. But, once again this equipment will be used to increase the recovery of higher grade material and not necessarily to cause major increases in overall yields or reductions in wood consumption.

Technology improvements such as computerized log shape scanning and computerized sawing decisions are available and are being adopted by some large mills. These systems provide better sawing consistency, closer tolerances and therefore reduced lumber target sizes, increased lumber yields and increased higher grade lumber output from lower quality logs.

A hardwood computer aided edging system has been developed to properly edge random width hardwood lumber and a more sophisticated system is being investigated that would provide the operator with information on how to obtain the highest grade after edging. Similar systems for hardwood trimming should be available in the future. These systems will be designed to increase grade output.

Improvements will continue to be made in hardwood lumber drying. They will improve grade recovery by reducing drying degrade. Most of the improvements will be a result of more control over the initial drying phase with the use of predriers and by better kiln drying with use of computer controls that allow smooth or continuous curve drying.

A system under development which will incorporate many of the above technologies and more is the Automated Lumber Processing System (ALPS). ALPS will include new techniques for log processing, board defect detection and optimum board cutting in order to maximize the yield of clear wood parts for furniture production. In an ALPS sawmill, logs are scanned internally to locate the position of internal defects. Computers use defect position information to determine and control log breakdown that maximizes grade or value yield of boards. After drying and superficial surfacing, video image analysis locates and classifies defects on each board. Computers use board defect information to determine and control board cutting to yield the maximum number of clear parts for a given cutting bill. Cutting is carried out by computer controlled conventional cutting or high-powered laser cutting. ALPS will increase the recovery of high grade material (McMillin et al. 1984).

Projected Lumber Recovery

The overall impact of changes in technology and other factors will be to improve both grade recovery and overall recovery. The modest assumption of 1% per decade increase in LRF for hardwood lumber processing seems reasonable. Table 136 shows average recovery of hardwood lumber by grade from various size trees for the late 1970s. Larger trees yield a higher proportion of higher grade lumber.[50] For the projections of hardwood lumber consumption in Chapter 7, it was assumed that overall hardwood lumber recovery increased 1% per decade in each tree size category. It was also assumed that the relative proportion of various lumber grades produced from a given size of tree remain constant. This assumption is conservative because improved technology is likely to improve the proportion of higher grade lumber obtained. Other factors that will tend to improve overall recovery and grade recovery are a moderate shift to use of a wider range of hardwood species and increased availability of slightly larger logs, on average, in the future. Slightly larger logs will be the result of increased inventory of hardwoods.

[50]Yield from trees includes all losses from parts of the tree stem initially considered usable to make lumber plus losses in the sawmill. These overall losses are estimated to be greater for trees of smaller diameter.

Softwood Plywood Processing

Plywood is a glued wood panel made up of thin layers of wood with the grain of adjacent layers at an angle, usually 90 degrees. Each layer consists of a single thin sheet, called a ply, or two or more plies laminated together with grain direction parallel. The usual constructions have an odd number of layers. The outside plies are called faces or face and back plies, the inner plies are called cores or centers. As compared to solidwood, the chief advantages of plywood are its nearly equal strength properties along its length and width, its greater resistance to splitting, and its size, which permits coverage of greater surfaces.

Two types of structural plywood are produced: sheathing and sanded. The chief distinguishing characteristic between the two is the quality of the face veneer(s). Sanded products require relatively clear veneer whereas sheathing grades tolerate knots and knotholes. Most structural plywood is sheathing grade and this is where oriented strand board and waferboard are competing.

Technology Developments

To improve profitability, softwood plywood mills have to increase wood use efficiency and reduce nonwood costs in several ways. Since sheathing can be made with lower quality veneer, sheathing mills can utilize smaller diameter, less expensive logs. The extent to which smaller diameter logs can be used, however, depends on the ability of the technology to deal with physical differences in logs as size declines. These include (1) a higher proportion of wet sapwood which decreases dryer capacity; (2) an increase in the proportion of the tapered part of the log relative to the cylindrical part, which decreases clipper capacity; (3) the rise in the fraction of the wood contained in the core, which decreases veneer recovery; and (4) the increased wood loss caused by a given error in centering the bolt in the lathe, which decreases overall veneer and full sheet veneer recovery.

Several technological changes have emerged over the last decade that address small log processing problems

Table 136.—Hardwood lumber recovery by size of tree harvested, late 1970s.

Tree diameter	Lumber grade			Total
	Higher grades	No. 1 Common	Lower grades	
inches	*Board feet lumber tally per board foot input*[1]			
11–15	.02	.07	.42	.52
15–19	.10	.25	.42	.76
19+	.20	.31	.37	.88

[1]Input is standing tree volume harvested as measured by the international quarter-inch log rule. The recovery ratios include loss of volume due to tree defects, hauling, storage and processing prior to entering the sawmill plus losses during sawmilling.

Source: Recovery data used in the Hardwood Assessment Market Model (HAMM). HAMM recovery figures are based on lumber recovery data by log grade in Hanks et al. (1980) and calculations of logs contained in various size trees, see Binkley and Cardellichio 1985.

(see table 137). In the past, plywood glues were unable to tolerate veneer moisture much above 4%. With modified High Moisture Veneer (HMV) glues now available, that limit has been increased to 12% and higher. Consequently, the wet sapwood of small logs can be accommodated in existing dryers by running the dryers faster. Added benefits are less veneer shrinkage, less breakage from too brittle veneer, and higher moisture in finished panels reducing warpage (Wellons 1988).

Clippers have traditionally been of the guillotine type with maximum running speeds of about 350 ft/min and much slower speeds for roundup (less than full width veneer from the tapered part of the bolt). A new clipper with a rotary cutting motion in place of the up-and-down motion of traditional clippers has become available and has been widely adopted. Clipper speed in excess of 500 ft/min during full sheet clipping can be achieved (Maxey 1977).

To maintain veneer recovery from smaller blocks, the core size and spinout rate have been reduced. This has been accomplished by supplying additional rotational power at the bolt periphery by powered rolls. Core sizes as small as 2 inches are being achieved (Knokey 1986).

In the area of charging, laser scanning is achieving more accurate bolt placement in lathes at speeds rapid enough to maintain throughput with small logs. Charging times approach 2 seconds. Microprocessor-controlled arms place the log into the lathe to achieve the largest possible cylinder, given bolt shape and other characteristics (Moen 1985).

To reduce the traditional labor intensive nature of plywood manufacturing, mills have automated several important facets of the process including green and dry veneer stacking, layup, and press loading. Hours of labor required to produce a thousand square feet of product can be reduced to about 2 from about 3-1/2 through this process of automation.

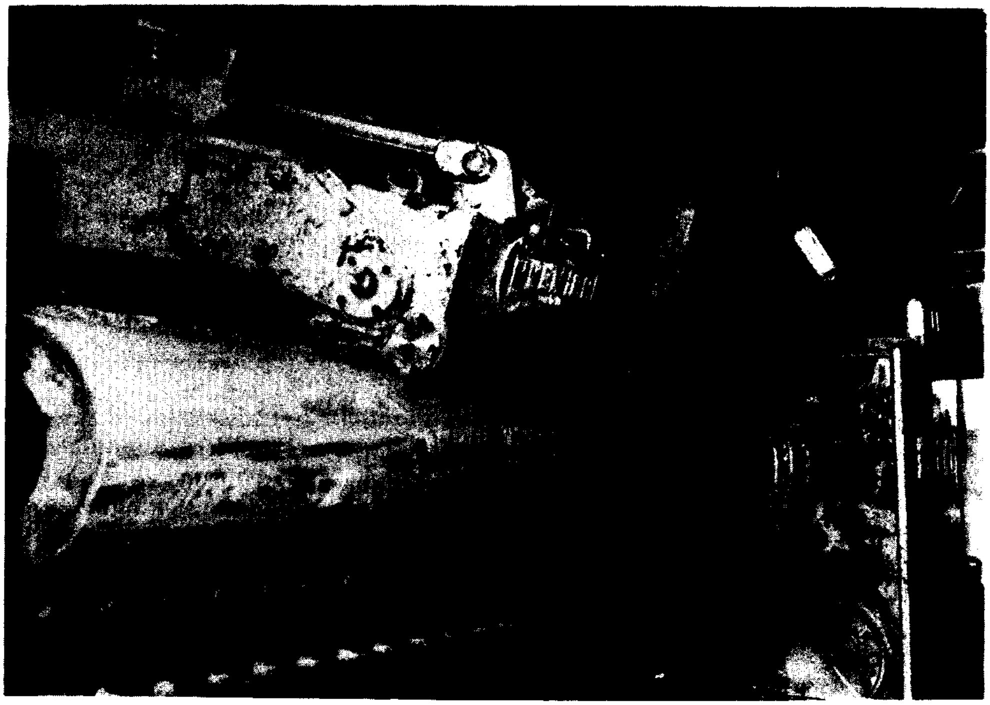
Projected Characteristics of Present and Future Panel Processing Systems

To quantify the effects of these and other technological changes, three mill designs were prepared to represent the level of technologies roughly equivalent to those available in the mid 1970s, the mid 1980s, and the late 1980s (see table 138).

Chief features of the mid-1970s design were (1) dropout cores of 5.25 inches, (2) spinout rate of 8% with average spinout core size of 9.5 inches, (3) charging time

Table 137.—Technological developments in structural panel processing.

Product type and development	Description	Impact
Softwood plywood		
Computerized lathe charging systems	Laser beams reflected off the bolt are analyzed by a computer to determine bolt shape from which the bolt's geometric center is determined	More accurate measurements of bolt's shape and easier maintenance increase veneer recovery
Hydraulic carriage drives	The rate of knife advance is controlled using a hydraulic drive in place of mechanical linkages	Reduced thick-and-thin veneer and increased on-target cutting
Powered nosebars and back-up rolls	Supplementary power to turn bolts provided by powered back-up roll and nosebar	Reduced incidence and size of bolt spinouts, fewer sliver plugups
High-moisture content gluing	Glue formulations with increased tolerance of moisture in veneer	Increased drier output
Radio-frequency redrying of veneer	RF redrying uses microwaves to redistribute moisture inside a stack of veneer eliminating wet spots	Reduced broken veneer and increased capacity of primary driers
Press pressure controls	High initial press pressures are reduced in increments during the press cycle	Permanent compression in panels is reduced allowing thinner target veneer thickness
Nonveneered structural panels		
Isocyanate binders	Isocyanate binders are used to replace phenolic resins to glue panels	Reduced energy requirements, shorter press times increase output on thicker panels
Long log flaker	Flaker produces flakes from random length logs	Reduced generation of fines and saw kerf
Continuous presses	Uninterrupted mat flow through the press	Reduced trim loss



The powered backup roll helps prevent veneer log spin-out by providing torque to the surface of logs. More veneer may be obtained by peeling logs to smaller cores. (Credit: Boise Cascade)

of 3 seconds per bolt, (4) average veneer thickness variation of 6%, (5) maximum clipper speed of 375 feet per minute, (6) conventional moisture target of 4% for veneer, and (7) no automation in veneer stacking, drying, layup, and pressing.

The mid-1980s design featured (1) dropout core size of 3.25 inches, (2) spinout rate of 3% with average spinout core size of 6.8 inches, (3) charging time of 2 seconds per bolt, (4) average veneer thickness variation of 3%, (5) maximum clipper speed of 500 feet per minute, (6) high moisture veneer target of 9%, and (7) automated green and dry veneer stacking, panel layup, and press loading. The late-1980s mill design differed from the mid-1980s mill design with respect to core size, which was 2 inches, and spinout rate, which was set at zero.

The average cost and recovery and optimum bolt diameter range were determined for each design using a mill simulation program.[51] Real energy and wage costs were assumed fixed at 1986 levels. Thus, projected changes in processing costs are due solely to changes in technology.

[51] *The Plywood Mill Analysis Program (PLYMAP) is an economic/engineering model of the plywood manufacturing process. PLYMAP calculates material flows and economic costs based on parameters describing machine capabilities and capacity at each discrete stage of plywood processing. It identifies potential bottlenecks, indicates areas of slack, and calculates overall revenues and costs for a given set of economic and process assumptions. The model has been documented by Spelter (in press). PLYMAP was used to compute recovery factors and processing costs of 3 mill types representing technology levels for the mid 1970s, the mid 1980s, and the late 1980s using parameters shown in table 138 and discussed in the text. A more detailed discussion of technologies in plywood mills is given by Spelter and Sleet (1989).*

Projected Mix of Panel Processing Systems

Average veneer recovery factors and costs were computed for three regions representing almost all softwood plywood manufactured in the United States: Pacific Northwest-West, Pacific Northwest-interior, and South. For each year in the forecast, a capacity mix of old, modern, and advanced technologies was projected in each region (table 139). Each technology type was assumed to process a distribution of log sizes determined by the simulation program to be optimal for that particular set of technologies and consistent with the overall reduction in average log diameter (table 140).

Rapid adoption of new technology is projected in all three regions. By the year 2010, old or mid-1970s equipment was projected to be completely phased out in the South and almost replaced in the West. Because of the higher proportion of old-growth timber in the West, the displacement of older technologies in mills specializing in sanded items was assumed to proceed more slowly.

Projected Recovery and Costs

Softwood plywood product recovery factors have tended to increase with increasing production of commodity sheathing which generates less residue and can use lower grade veneer. Increased use of smaller but less defective second-growth timber has also helped boost recovery. Veneer recovery in plywood mills is estimated to average about 50% of the cubic volume of wood processed. Higher recovery is projected with the mix of capacities shifting to modern and advanced equipment.

Table 138.—Current and projected designs of softwood plywood systems.

Process parameters	Technology type		
	Mid-1970s	Mid-1980s	Late-1980s
Percent of bolts which spinout	8	3	0
Spinout core size (inches)	9.5	6.8	N/A
Target core size (inches)	5.0	3.3	2.0
Ratio of actual-to-nominal veneer thickness	1.024	1.000	1.008
Ratio of thickness variability to actual veneer thickness	.055	.032	.040
Clipper speed (fpm)	375	500	500
Target veneer moisture (percent dry basis)	4.5	9.0	9.0

Table 139.—Proportion of various softwood plywood systems by region in 1985, with projections to 2040.

Section and region	1985	Projections				
		2000	2010	2020	2030	2040
South						
Mid-1970s	40	5	0	0	0	0
Mid-1980s	60	70	65	63	62	60
Late-1980s	0	25	35	37	38	40
Pacific Coast						
Pacific Northwest						
Pacific Northwest-West						
Mid-1970s	70	30	20	17	16	15
Mid-1980s	30	55	52	51	50	50
Late-1980s	0	15	28	32	34	35
Pacific Northwest-East						
Mid-1970s	40	20	15	12	10	10
Mid–1980s	60	68	65	60	55	55
Late-1980s	0	12	20	28	35	35

Table 140.—Trend in diameter of softwood veneer logs processed by plywood mills, by plywood mill system and region in 1985, with projections to 2040.

Section and region	1985	Projections				
		2000	2010	2020	2030	2040
	Inches					
South						
Mid-1970s	12.0	12.5	12.7	12.6	12.5	12.4
Mid-1980s	11.0	11.0	11.0	11.0	11.0	11.0
Late-1980s	9.0	9.0	9.0	9.0	9.0	9.0
Pacific Coast						
Pacific Northwest						
Pacific Northwest-West						
Mid-1970s	15.5	14.8	14.5	14.3	14.1	14.0
Mid-1980s	14.5	13.0	12.5	12.1	11.7	11.5
Late-1980s	12.0	11.8	11.5	11.0	10.6	10.2
Pacific Northwest-East						
Mid-1970s	15.5	14.5	14.0	13.5	13.2	13.0
Mid-1980s	14.0	12.5	12.0	11.7	11.6	11.5
Late-1980s	10.0	10.0	10.0	10.0	10.0	10.0

This occurs despite the drop in average bolt diameters that would tend to depress recovery. Overall recovery is expected to increase by 6% in the Pacific Northwest-West and 20% in the South between 1985 and 2040 (table 89); average U.S. recovery would rise by 15% to 58% by 2040.

Processing costs are also projected to decline by about 5–7% in real terms between 1985 and 2040 (table 83). This development continues historical trends (interrupted briefly by rising energy costs in the 1970s) toward lower real manufacturing costs in plywood and is a direct outgrowth of labor and material saving technologies installed in modernized facilities.

The Impact of Technology Change on Plywood Manufacturing Costs

Plywood manufacturing costs include costs for stumpage, harvesting and hauling, and processing. The technology changes discussed previously hold down the cost of making plywood by decreasing the delivered cost of logs per unit of plywood output and by holding down plywood mill processing costs.

Projected improvements in plywood recovery will hold down the cost of logs as a component of plywood costs. Even though delivered log costs for the Pacific Northwest-West and South are projected to increase by 10.2% and 13.0% per decade through 2040 respectively, the cost per unit of plywood output increases only 9.8% and 10.5% per decade, respectively (fig. 80). Technological change is projected to be more effective in holding down log costs as a component of plywood costs in the South due to smaller projected declines in log diameters.

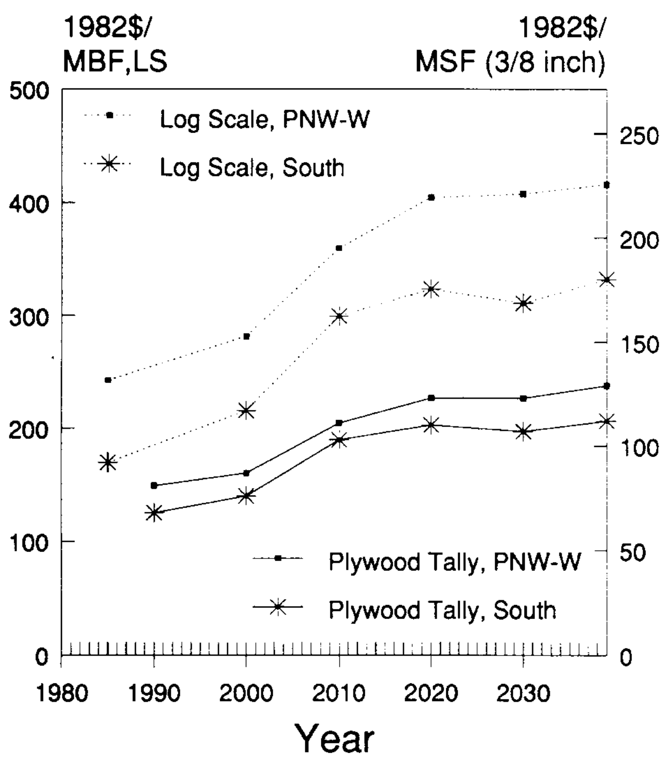


Figure 80.—Delivered log cost for softwood plywood, PNW-West and South.

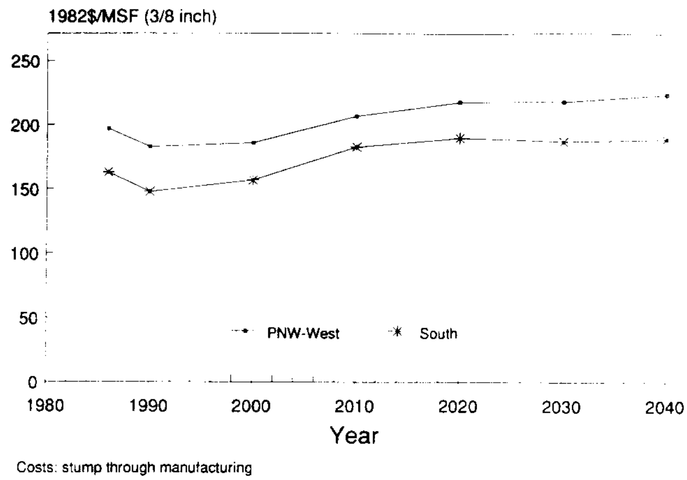


Figure 81.—Total softwood plywood-making costs, PNW-West and South.

Projected improvements in plywood processing costs will further shield the cost of making plywood from projected increases in log costs. Even though delivered log costs for the Pacific Northwest-West and South increase by 10.2% and 13.0% per decade through 2040, total manufacturing costs increase only 2.4% and 2.7% per decade on average (fig. 81). Most of the projected increase occurs by 2010 to 2020. Technological change in both regions is projected to maintain a nearly constant level of comparative advantage for the South in plywood manufacturing costs relative to the Pacific Northwest-West over the projection period (fig. 81).

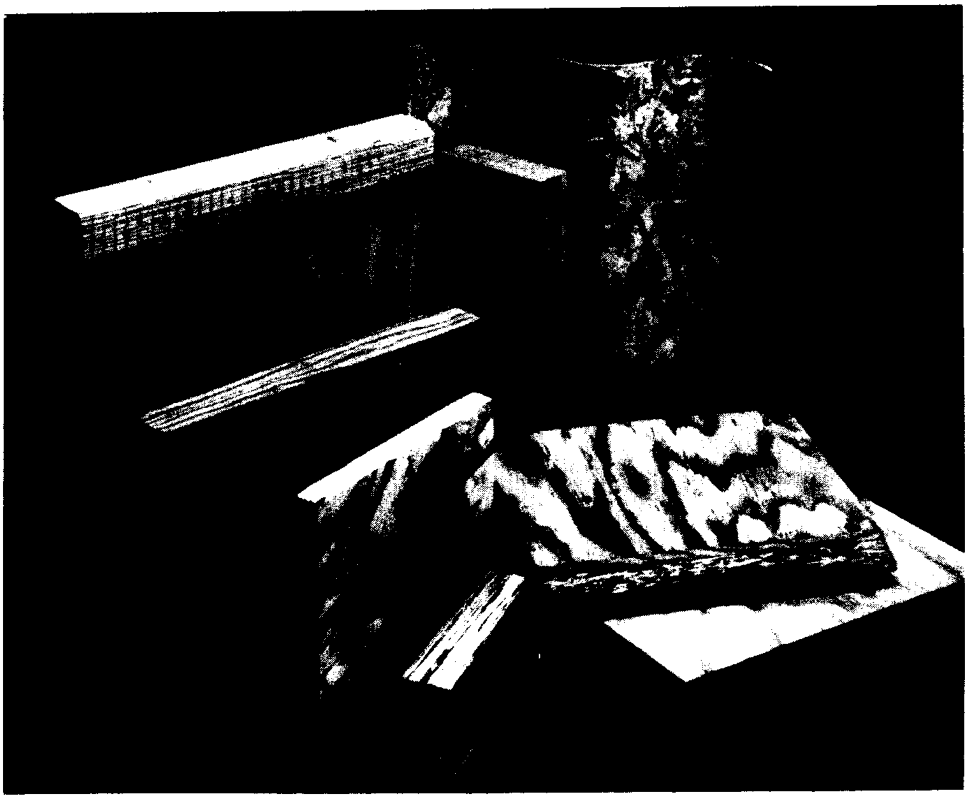
Nonveneered Structural Panel Processing

Nonveneered panels consist of wood wafers or strands smaller than veneer sheets but larger than wood fiber. Unlike conventional particleboards, the raw material for structural products normally comes direct from roundwood sources rather than mill byproducts; adhesives used are exterior rather than interior type; particles are usually aligned in several discrete layers rather than laid down at random.

Technology Developments

Technology developments in processing oriented strand board and waferboard are likely to focus on two areas: increasing their range of applications and decreasing wood loss during the flaking, forming, and trimming processes.

Oriented strand board and waferboard have been used as sheathing in walls and roofs, and for floor underlayment, and technology has more recently been developed for applications such as concrete forms and siding. Suitable performance is being achieved by using phenolic paper overlays to stabilize the surface and provide a



Examples of structural composite products, from top left: wood joist with laminated veneer lumber (LVL) flange and plywood web, wood joist with LVL flange and wood particle web, waferboard and subfloor/underlayment, Parallam (reg. trademark of McMillan Bodel Inc.), conventional plywood, COM-PLY (reg. trademark of the American Plywood Association), LVL, and Waveboard (reg. trademark of the Alberta Research Council). (Credit: Forest Products Research Society)

suitable basis for paint or concrete forming. To improve panel stability, the trend has been to displace phenolic adhesives, either totally or in part, with isocyantate adhesives. While more costly than phenolics on a pound for pound basis, isocyanate adhesives are more profitable for a given level of panel stability than phenolic adhesives because they allow shorter press times and more moisture in the furnish.

Better flaker designs are likely to be adopted in the future to reduce the generation of fines (pieces of wood too small to be used) and improve forming techniques to increase wood utilization. Disc flakers are normally used in mills today. These machines normally require logs to be reduced to 4-foot bolts for processing. The flakers generate from 8–10% small particles (fines) that are unsuitable for use in panels along with about 4% kerf losses caused by the primary and secondary slasher saws. To reduce these losses, whole log flaking utilizing ring and disk waferizers, with losses due to fines also in the 8–10% range but lower slasher kerf losses of about 2%, seems likely to be adopted (Pallmann GMBH 1987).

In current practice, fines are burned for fuel, but with improved mat formers, some of the fines could be used in the core layer of panels without reducing panel strength. This can be accomplished by electrostatically orienting particles. Panel strength increases as uniformity of particle alignment improves (Fyie et al. 1980). Electrostatic orienters achieve higher orientation ratios than mechanical orienters, thus achieving panel strength with smaller particles that are as good as mechanically oriented panels with standard size furnish. The effectiveness of electrostatic orientation, however, decreases with large particle sizes, thus electrostatic orientation will likely complement mechanical formers rather than displace them (Buecking et al. 1980).

Another means to reduce wood losses is to employ continuous presses now gaining acceptance in particleboard and medium density fiberboard facilities. Continuous mats would eliminate end trimming resulting in wood savings of 1–2%. But the larger size and rougher surface of oriented strand board and waferboard furnishes wear out the steel bands used in these presses and for that reason their adoption by industry appears unlikely (Soine 1988).

Projected Recovery and Costs

Nonveneered structural panel wood recoveries are estimated to average between 55% and 60% (based on losses of 4% for trimming log ends and log rejects, 8–12% for fines, 35–38% for panel densification, and 3% for panel trim). This rate of recovery is projected to increase about 2% between 1986 and 2040 due to improvements in bolt preparation and flaking and more complete utilization of fines (table 90).

Oriented strand board and waferboard manufacturing costs have decreased during the past 5 years because of savings made possible by improved glue blenders. Resin dosages of liquid phenolic resins have declined from over 5% to less than 4%. Powdered resin dosages have also been reduced from 3% to 2%. Further potential for savings in this area is limited, so the projections of processing costs for waferboard show more modest declines than those for plywood. The adoption of modern technology by remaining mills is expected to account for the bulk of the projected 4% reduction in processing costs between 1986 and 2040 (table 84).

Pulp, Paper, Paperboard and Related Products

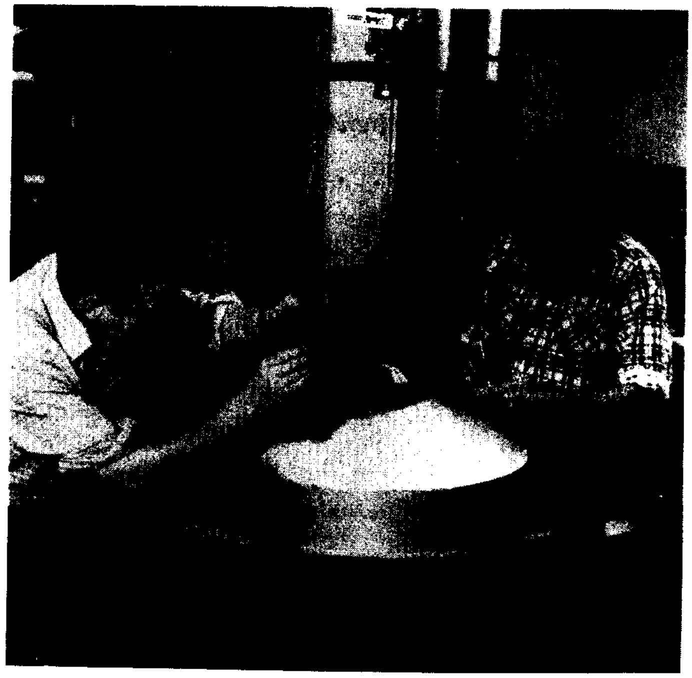
Paper and board products are made primarily from new or recycled wood fiber. New wood fiber is in the form of woodpulp which is made from pulpwood. Recycled wood fiber is derived from wastepaper which consists of old newspapers, old corrugated containers, mixed grades, pulp substitutes, and high grade deinking. Different paper and board products use different mixes of woodpulps, wastepaper, and other fiber. This mix, or fiber furnish, reflects the requirements for a particular product grade, the level of technology, and the availability of fibers.

Paper and board products are classified into paper grades and paperboard grades. The major paper grades include tissue (sanitary products, napkins, toweling), printing and writing (bond paper, computer paper, copying paper, and paper for books and magazines), packaging and industrial (wrapping papers, bags, and sacks), and newsprint. The major paperboard grades include unbleached kraft (linerboard for corrugated boxes), semichemical (corrugating medium for boxes), solid bleached (folding boxes and food containers), and recycled paperboard (a variety of products including gypsum wallboard facing).

Although specific manufacturing processes and fiber requirements differ among the product grades, paper and board processing generally involves wood handling (debarking, chipping, and chip screening), pulping and bleaching (conversion of chips into pulp using chemical or mechanical processes, bleaching when needed), stock preparation (repulping, deinking, and removal of other contaminants from wastepaper furnish, fiber refining, mixing pulp with additives and recycled fiber), and conversion to paper and board (sheet formations, pressing, drying).

Technological Developments

Technological developments in the U.S. paper and board industry focus on the ability to improve production efficiency and product quality while mitigating or eliminating negative impacts on the environment. Some of the technical challenges facing the industry include the need to reduce energy costs, reduce capital equipment costs, improve strength and quality of recycled fiber, increase fiber recovery, develop processes that can use more hardwood fiber, develop processes that are more environmentally benign, and provide better quality paper products for present and future uses.



An experimental spinning disk separator takes a stream of recycled paper slurry and spins sticky contaminates to an outer ring while dropping useable pulp fiber to an inner ring. (Credit: USDA Forest Products Laboratory)

Many current and likely future technological developments address the above challenges. Table 141 provides a list of such developments in paper and board processing, describing the likely impact of each development on wood requirements. These developments are viewed as very likely to take effect over the next 50 years. They were incorporated into the projections of paper and board, woodpulp, and pulpwood production shown in Chapter 7 (Ince et al., in prep.).

Table 142 lists those technological developments that were considered, but not included in the projections. They were not included because they were viewed by industry, university, and government researchers as less likely to be commercially significant during the next 50 years.

Paper and Board Manufacturing Processes

As mentioned above, each paper and board product grade uses specific production processes. These processes can be defined in terms of the percentages of fiber used, the nonfiber manufacturing costs, and the date of commercial availability. Technological developments result in new, more cost-effective processes which use increasing amounts of wastepaper and mechanical pulps and have lower nonfiber manufacturing costs.

Table 141.—Technological developments in pulp and paper processing included in the projections.

Type of development	Description	Impact
Meeting needs for improved stacking strength in corrugated boxes	Edgewise compressive strength eventually becomes the principal performance criterion	Compressive strength is improved with higher density linerboard, increased use of higher-yield pulps and more hardwood; improved quality control in kraft linerboard
Meeting increasing demands for quality and uniformity in printing and writing papers with improved papermaking technology	Increased use of higher quality fillers, drainage and retention additives, coating pigments, and hardwood fiber; more machine finishing and alkaline papermaking	Less total wood fiber use per ton of product; lower basis weight with more uniform quality; more hardwood
Meeting demand for printability and quality in linerboard with improved forming and finishing technology	Development of multi-ply forming; improved stock preparation systems; use of hardwood fiber for printability on the surface, or sandwiching hardwood or recycled fiber in the core for economy	Higher proportions of hardwood fiber and recycled fiber in unbleached kraft paperboard; separate pulping and refining for hardwoods and softwoods
Gradual replacement of traditional groundwood pulp by modern mechanical pulps in newsprint and other groundwood papers	Thermomechanical (TMP), Chemithermomechanical (CTMP), and pressurized groundwood (PGW) replace some older groundwood and refiner processes, with improvement in pulp quality	Wider market potential for higher yield mechanical pulp; greater ability to substitute for lower yield chemical pulp
Improvement in pulp bleaching systems to reduce capital costs and operating costs, and to meet environmental objectives	Adoption of short-sequence bleaching systems, chlorine dioxide in bleaching, and lower yield in bleached kraft pulping; development of peroxide and other bleaching technologies for TMP and CTMP; use of higher yield bleached mechanical pulps	Greater use of bleached mechanical pulps will reduce wood input requirements, although lower yield kraft pulping will increase wood requirements
Modernization of equipment and processes in older mills to improve efficiency and reduce costs	More tree-length wood handling and chip thickness screening; improvements in stock preparation, paper machine systems, and kraft chemical recovery; energy savings through use of variable-speed drives, high-efficiency motors and upgraded turbine generators; use of more wood or bark for fuel	Lower wood requirements due to gains in wood utilization efficiency, especially in older bleached kraft and sulfite mills; offset somewhat by more use of wood for fuel
Better recycled fiber recovery, improved contaminant removal technology for wastepaper furnish, and increased use of recycled fiber; technological responses to increased supply of recyclable paper	Improved centrifugal cleaners, slotted screens, deinking systems, and high-consistency refining; technology for removal of contaminants such as "stickies"; chemical treatment to restore some bonding strength to recycled fibers	Modest growth in recycled paperboard production, but substantial growth in use of recycled fiber in traditionally virgin fiber grades, such as kraft linerboard, semichemical corrugating medium, newsprint, and tissue
Displacement of chemical pulp fractions by modern high-yield mechanical pulp, in newsprint and tissue, and to some extent in printing and writing paper, reducing capital requirements and wood costs	TMP and CTMP with higher percentages of hardwood fiber will replace some chemical pulp fractions in newsprint and tissue, providing better opacity and bulk; substitution in printing and writing limited by color reversion and brightness	Higher yield and cost savings; increased use of hardwoods with CTMP
Continued adoption of improved pressing technology in papermaking, reducing sheet drying costs, increasing throughput, and improving product quality	Wide-nip and high-impulse press sections will continue to be installed in linerboard mills, and will be installed in mills producing other grades	Increased ability to use hardwood and recycled fiber in kraft linerboard; higher production rates; energy and capital cost savings
Commercial adoption of impulse drying, press drying, or related improvements in pressing and drying technology	Interfiber bonding and substantial strength improvements with higher yield pulps, especially with hardwoods, result from drying under pressure or simultaneous pressing and drying	Substantial savings in capital, energy, and wood requirements; increased use of higher yield pulp and more hardwood in grades like kraft linerboard
Further development of nonwoven products and improvements in sanitary products based on fluff pulp	Innovation in sanitary products and new durable nonwoven products; use of new specialty market pulps; some displacement of woodpulp by "superabsorbent" additives	More efficient use of wood fiber per unit in sanitary and nonwoven products; more use of bleached CTMP
Development of laminated paper and packaging products	Development of laminated or coextruded packaging structures based on paper or paperboard with plastic or metal foil surfaces	Expanded product market potential, but lower wood use for current paper and board packaging
Continued displacement of some fiber products by plastics and other substitutes	Continued innovation and substitution of plastics in packaging, especially food packaging, bag and grocery sacks, and shipping containers; use of synthetic polymers to reinforce paper and paperboard	Decline in the long-term rate of growth in demand for packaging grades relative to GNP and population growth

Table 141.—Continued.

Type of development	Description	Impact
Substitution of paper by electronic means of communication and information storage	Gradual long-term displacement of print media and written communication by electronic and computer technology; short-term complementary effects on demand for printing and writing paper	Decline in the long-term rate of growth in demand for newsprint and printing and writing grades relative to GNP and population growth
Regulation related to recycling	Decreasing availability of sanitary landfill capacity and escalating waste disposal costs are prompting legislative initiatives on recycling	Increased supply of recycled fiber from wastepaper
Increased demands for product uniformity and quality control; better control of inventory in packaging and shipping	Improvements in instrumentation and on-line testing for product quality control, mill test labs, and computer controls in production;	With the assurance of better quality control and uniformity, lower basis weights will be acceptable in some markets; more consumer demand will be satisfied per ton of product output

Table 142.—Potential technological developments in pulp and paper processing not included in the projections.

Type of development	Description	Impact
Expanded use of new chemical treatments to improve properties of paperboard products	Chemical impregnation to increase strength and moisture resistance; chemical saturation for flame resistance	Improved product performance can be achieved for specialty applications
Expanded use of anthraquinone (AQ) in kraft, sulfite, and soda pulping	AQ additives provide marginal enhancement of chemical pulping processes; neutral sulfite AQ process is an alternative to bleached kraft for high tensile strength products	Marginally higher pulp yield is achieved, but concept is limited by cost of AQ chemical, plus differences in capital and energy inputs
Biological fiber treatment, and "biopulping"	Pretreatment with biological lignases or fungi prior to mechanical pulping; treatments could include biobleaching	Improved efficiency in mechanical pulping processes with application of biotechnology, but development is in early stages
Advances in biological effluent treatment systems	Use of microbial agents for decolorization, removal of waste, and improvement in effluent treatment systems	Improved efficiency in effluent control and waste treatment; potential impact on optimal pulp yield or pulping process
Commercial development of nonsulfur chemimechanical pulping process (NSCMP)	Potential application in corrugating medium and linerboard mills; a relatively high yield process suitable for small or medium size mills using hardwoods or mixed species	Elimination of inorganic sulfur emissions; less wood input with higher pulp yield
Organisolv pulping	Development of pulping processes based on organic solvents instead of water; includes alcohol pulping as a substitute for kraft, and ester mechanical pulping with chemical recovery	Economic advantages derive from higher yield and lower capital costs; likely to require additional development
Fiber-based structural products	Development of molded fiber structural components and products; includes potential products reinforced with high-strength polymers or carbon fibers;	New product market potential for use of wood fiber in high performance products, but mass-commodity markets likely to be met by lower cost solid-wood products
Production of new food substances for animals or humans using wood or pulpmill by-products	Traditional examples include vanillin, torula yeast, animal feed molasses, shiitake mushrooms, wood chip animal fodder and ruminant feed	Product development likely to be limited except in a national emergency
New chemicals from wood	Various chemical feedstocks can be produced from wood, in addition to the conventional silvichemicals, naval stores, lignosulfonates, and other pulp mill by-products; direct acid hydrolysis, "wood-to-oil" processes, and fermentation offer alternatives	Technologies will remain available, but will not likely be developed so long as adequate supplies of petroleum, coal, and other resources are available at low cost
Substitution of wood fiber by kenaf or other natural fibers	Kenaf, bagasse, straw, cotton, and other natural fibers are used for specialty products, or in regions of the world with scarce wood resources	Limited development potential in the United States because of abundant wood resources

Table 143 describes the processes used to make selected paper and board grades. The table describes those processes which are currently available as well as those future processes that are expected to become available in the next 50 years. For example, in making newsprint, there are four processes which are currently used. Newsprint processes one and two use mostly mechanical pulp with smaller fractions of chemical pulps. Newsprint process three uses only wastepaper, and has a lower nonfiber manufacturing cost than processes one and two. Newsprint process four uses equal amounts of mechanical pulp and wastepaper. Another example is unbleached kraft, for which two current processes and two future processes are identified. Unbleached kraft processes one and two use principally chemical pulp with only a small portion of wastepaper. Unbleached kraft process three, a future process, uses higher yield kraft pulp and more hardwood. Another future process, unbleached kraft process four, shifts a substantial portion of the furnish to high yield mechanical pulps, while further increasing the amount of wastepaper used. Nonfiber manufacturing costs are the highest for process one and the lowest for process four.

The projections of paper and board, woodpulp, and pulpwood in Chapter 7 are based, in part, on projections by product grade and process. Figures 82 and 83 show the production of unbleached kraft and newsprint by process. For unbleached kraft, the projections show a shift from processes one and two to processes three and four. Newsprint process three, which uses only wastepaper, is projected to become the dominant process for manufacturing newsprint in the United States, although the Canadians are expected to continue to make newsprint largely from raw wood fiber.

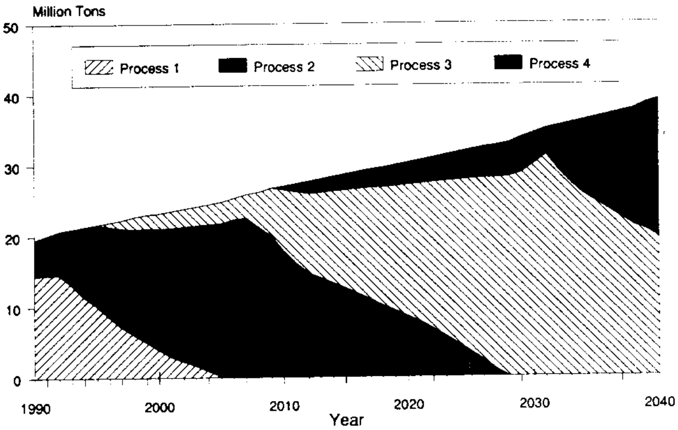


Figure 82.—Unbleached kraft production in the United States by process.

Table 143.—Fiber consumption and date of availability of paper and board manufacturing processes, by product grade.

Product grade	Chemical pulp (Fiber consumption)	Mechanical pulp (Fiber consumption)	Wastepaper (Fiber consumption)	Nonfiber costs per ton of product	Date available[1]
	Percent			*1986 dollars*	*Year*
Newsprint					
Process One	25	75		360[2]	—
Process Two	9	91		386[3]	—
Process Three			100	351[2]	—
Process Four		50	50	399[4]	—
Unbleached Kraft					
Process One	93		7	177[3]	—
Process Two	85		15	158[3]	—
Process Three	85	15		140[3]	1,995
Process Four	50	30	20	133[3]	2,010
Semichemical					
Process One	60		40	201	—
Process Two	90		10	214	—
Process Three		100		215	2,000
Solid Bleached					
Process One	100			460	—
Process Two	37	63		370	1,995
Recycled					
Process One			100	230[3]	—

[1]*No year is specified for processes that are currently available.*
[2]*North and South.*
[3]*South.*
[4]*Rocky Mountains and Pacific Coast.*

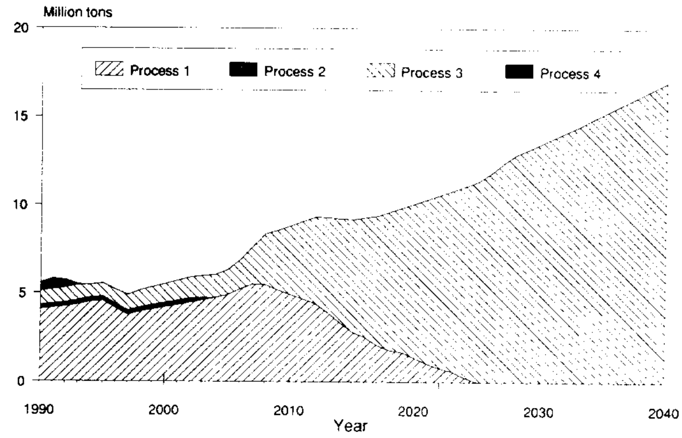


Figure 83.—Newsprint production in the United States by process.

Wood Product Use in Construction

Construction, and repair and alteration of houses, apartments and nonresidential structures use most of the structural lumber and structural panels that are produced (tables 95 and 98). There are many opportunities to improve construction practices to reduce the volume of wood used while maintaining the quantity and quality of construction (Row and Hagenstein 1988). There are also opportunities to expand wood use, such as use of wood in place of concrete in making residential housing foundations.

Possible Changes in Technology

There are many ways to save wood in construction because most wood structures are built stronger than needed (NAHB Res. Foundation 1971). Although this has long been recognized, builders continue to rely on conservative practices that waste material. For example, 90% of exterior wall framing is spaced at 16-inch intervals (McKeever 1988) even though 24-inch spacing gives adequate strength for one-story homes and the top floor walls of multistory structures. Similarly, 91% of interior walls space framing at 16-inch intervals. Even in roofs, where structurally efficient wood trusses are widely used, 28% of roof framing is placed at 16-inch intervals.

Overdesign is partly a holdover of practices imposed by older technologies. Sixteen inch spacing probably stems from the time when walls were plastered over wooden lath. Tradesmen found it difficult to plaster on lath when studs were spaced more than 16 inches apart. In modern times, most walls are finished with plasterboard that easily spans 24 inches. Approximately 400 board feet of lumber could be saved in walls and partitions of a typical single-family home by converting to 24-inch spacing.

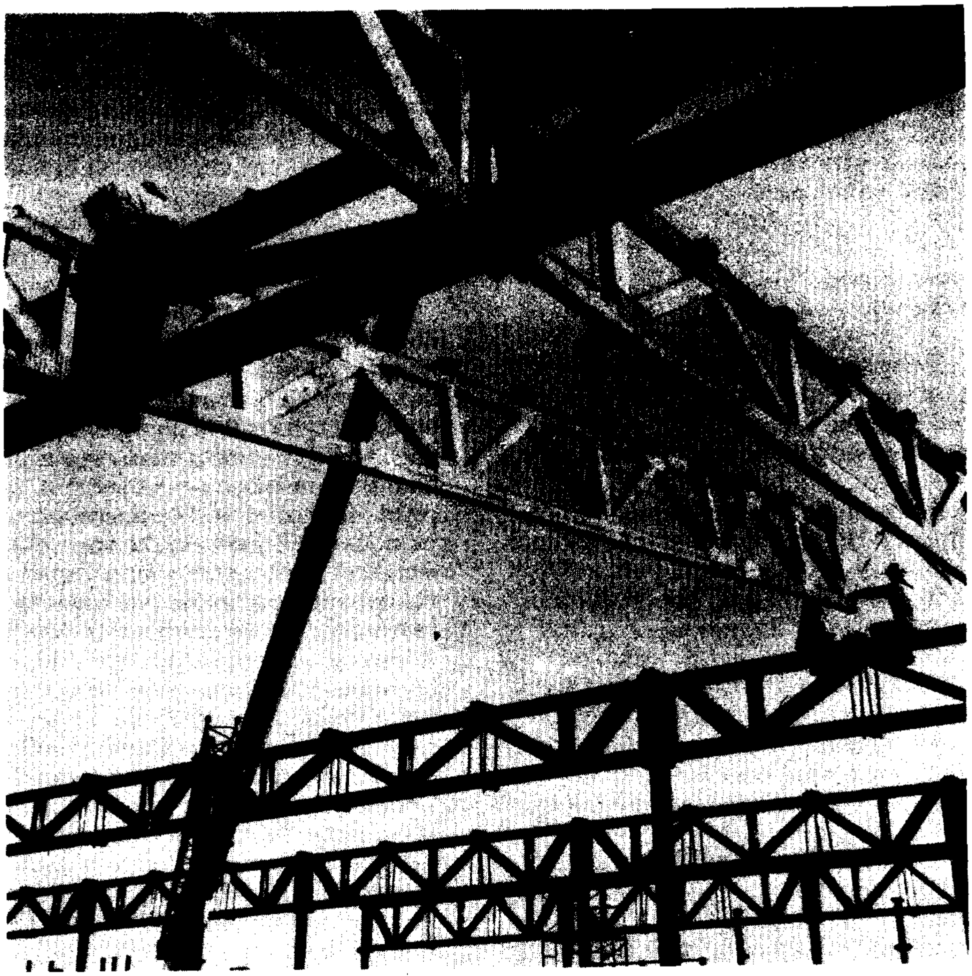
Where walls intersect to form corners, it is necessary to provide supports for finish wall sheeting. This has traditionally been done by using an additional stud at intersections. Three-stud corners could be replaced by metal brackets that are available to support wallboard. In a typical home, the elimination of 3-stud corners could save about 100 board feet.

Overdesign extends to floors where bridging between joists and overlapping of joists on the center girder are common. But bridging adds nothing to the strength of a floor, and joints that are butted on the center girder instead of overlapped can be adequately held together by metal plates and plywood subflooring. Additional material could be saved by using 1-inch boards for header joists (at the end of the floor joists) instead of 2-inch stock. Shorter joists may be used with an "in-line" joist system where one joist is cantilevered (extended) over the center girder and held to a second shorter "in-line" joist by a structural splice. Stress is reduced in the overhanging (extended) joist. Structurally sound floors have also been built using only 1-inch wide stock, but this reduces the nailing surface (Hanke 1986). A more practical approach is to continue to use 2-inch stock, but with narrower dimensions such as 2x8s instead of 2x10s. The amount of lumber saved by using smaller joists, thinner headers, and butted joints is about 700 board feet in an average size home; but the nationwide impact of such a change would be about half that savings per home since about half of new homes are built on a concrete slab and use no lumber for flooring.

Adoption of "optimum value engineering" practices such as those listed above could save 10–15% of the dimension lumber required in a conventional house. Another way to economize on wood use in a building is to develop more efficient building materials. The metal plated wood roof truss is one example. Roof trusses transfer loads to exterior load bearing walls, eliminating outward thrust and the need for interior load bearing walls. Wood roof trusses are widely used in all construction sectors in increasingly diverse shapes and configurations. A high percentage of residential structures already use trusses; thus, increased savings due to expanded use in housing is limited.

A more recent wood saving product is the prefabricated wood I-joist. I-joist design recognizes that the most critical parts of a member are its top and bottom edges. Accordingly, most of the material is contained in the two flanges (the edges). The flanges are connected by a web of plywood or structural flake board. I-joists are usually used in floors where they replace traditional 2x10 and 2x12 joists, but they can be used for longer spans up to 40 feet. Because they are a fabricated product, they can be made in continuous lengths. They are also less likely to shrink and swell over time and thereby reduce the likelihood of squeaky floors. They are lighter and stronger than lumber, and precut holes in the web easily accommodate piping and duct work. Web stiffeners are required at points where they support load bearing walls and lateral support is critical in many applications.

Another engineered product that saves wood is laminated veneer lumber (LVL). LVL is a solid structural product made from 1/10 or 1/8-inch thick veneers, laid together in parallel grain pattern, coated with waterproof adhesives which are cured by heat and pressure, with lengths ranging up to 80 feet. It is somewhat stronger



Engineered wood structural members are used frequently in nonresidential structures. (Credit: USDA Forest Products Laboratory)

and stiffer than lumber. LVL has been used for flanges of I-joists, headers and beams, concrete forms, scaffold planks and partition framework. It has found uses in prefabricated housing where its higher strength is better able to resist forces while house sections are moved.

Structural members are also being made from reconstituted strands of wood. A product is being made by laminating long strands of wood with exterior adhesives and heat pressing into shapes similar to dimension lumber. Its properties and uses are similar to those for LVL.

Stressed skin panels, consisting typically of two outer layers of plywood or oriented strand board with foam insulation in the core, can reduce wood use in timber frame residential construction and construction of industrial and commercial buildings. In timber frame construction and many industrial/commercial buildings, the loads are carried by a few key members. The intervening bays require only a nonload bearing wall. This means that the structural requirements on the wall are less than for walls in light frame construction. A conventional built-up system using 2x4s and foam sheathing results in overdesigned wall sections and inferior insulation. In contrast, stressed skin panels require less lumber and provide superior insulation performance. These panels may be used in roofs as well as walls in industrial/commercial buildings.

Decay of wood in structures due to moisture is a serious problem and an increasing concern since insulation in walls has increased which may lead to greater condensation. Correcting this problem will hold down need for wood use in repair. Under winter conditions, humidity from the building enters into the framing cavities and condenses. This reduces the R value of the insulation, and promotes fungus growth, which leads to decay. Proper installation of polyethylene vapor retarders avoids the problem, but proper installation is difficult in practice because of the many breaks in the sheet to accommodate electrical outlets and the like. An alternative system, called the Airtight Drywall Approach (ADA), uses gaskets between the framing and the interior drywall only (Lstiburek 1985). The vapor retarder is the painted drywall. The system is based on the idea that infiltration through gaps in the barrier, rather than the permeability of the barrier, is the chief cause of excessive vapor transmission. By closing off infiltration routes with gaskets, infiltration is decreased, and drywall is less likely to be inadvertently punctured during construction than a plastic barrier. Studies have shown that if air vapor movement from the inside of the structure is controlled, moisture build-up in insulated walls is not severe enough to cause structural decay.

The rate of adoption of the wood saving techniques mentioned above will depend in part on the in-place costs of wood products and the resultant pressure to reduce wood cost and wood use.

Substitution Between Wood and Nonwood Materials

Wood use may decrease or increase in certain types of construction as its competitive position changes with respect to steel and concrete. In evaluating suitability for various types of construction, wood products are compared to steel and concrete in structural capability, fire resistance (in large structures), insulation, and cost.

The main structural property of concrete is its compressive strength. In addition, reinforced concrete possesses good tensile strength. But these favorable properties are in excess of what is typically required in residential and smaller commercial structures. At over $100/cubic yard, this material is expensive for the required performance levels in such structures. Moreover, other positive features of concrete, such as its fire insulating capabilities and low sound transmission, become crucial factors only in large structures. The superior strength of concrete becomes economic only when it is fully utilized, e.g., in larger structures. Thus, no major displacement of wood by concrete is expected in most construction markets.

One area where concrete is used in light frame construction is for basement walls and footings because it is impervious to decay by soil organisms. Improper curing, however, may lead to basement walls that leak and opportunities to use treated wood products for foundations. A chemically treated but otherwise conventional stud and plywood wall may be placed over a coarse gravel footing. The key element is a drainage path through the gravel to a gravel bed under the floor where the water collects and is removed by a sump pump or is diverted by pipe to daylight. By not allowing moisture pressure to build up, leakage is eliminated, and the chemical treatment makes the structure durable and lasting. Preserved wood foundations generally cost less than poured concrete and are slightly more economic than concrete block due to speed of installation (Spelter 1985a). But quality control requirements (use of galvanized steel nails, proper chemical treatment, proper installation technique, etc.) are strict and the system has not been as widely adopted as initially thought, although many homes in colder climates have been built with chemically treated wood foundations.

Like concrete, steel has superior strength properties compared to wood, and can cost less than wood in some cases. But the rate that heat is conducted through a 2x4 steel stud is about two and a half times that conducted through a wooden stud. Sound transmission through steel is also greater. These drawbacks cannot be overcome without incurring expenses that negate what initial economic advantage may exist. Nevertheless, steel construction is more likely than concrete to displace wood, particularly in larger residential and mid-sized commercial structures. The degree of displacement will depend on relative changes in in-place wood and steel costs.

Projected Wood End-Use Rates in Construction

Projected wood use rates in this analysis take into account the potential effects of technology developments mentioned above and the expected changing competitive position of wood materials compared to steel and concrete. The rate of change in use rates is driven by the economic pressure of changing in-place wood prices and changing in-place prices for steel and concrete. Higher prices for wood will increase adoption of wood saving practices and decrease the competitiveness of wood versus steel and concrete in selected applications. Under the economic scenario portrayed in the base projections in Chapter 7, use of softwood lumber per square foot of floor area in residential construction declines by 24% between 1986 and 2040 (table 144). Total structural panel usage is more stable, however, because one consequence of more efficient lumber use is a need for thicker structural panels in walls, roofs and floors.

Wood needed per household for repair and alteration is projected to remain relatively constant for softwood lumber and plywood, but is expected to increase for oriented strand board and waferboard. Wood use per dollar of nonresidential construction is projected to remain stable for softwood lumber, and rises slowly for structural panels as declines in use of softwood plywood are offset by increases for oriented strand board and waferboard (table 145).

Table 144.—Single-family and multifamily average floor area and wood product use per square foot of floor, 1986, with projections to 2040.

Year	Average floor area	Softwood lumber	Structural[1] panels
	Square feet	*Bd. ft./ sq. ft.*	*Sq. ft. 3/8-inch basis per sq. ft.*
		Single-family housing	
1986	1825	6.3	3.4
2000	1950	5.9	3.2
2010	1975	5.5	3.3
2020	1990	5.2	3.3
2030	2000	5.0	3.2
2040	2010	4.8	3.2
		Multifamily housing	
1986	956	4.2	2.6
2000	1065	4.0	2.5
2010	1080	3.9	2.5
2020	1090	3.7	2.5
2030	1100	3.6	2.5
2040	1100	3.6	2.5

[1]*Softwood plywood and oriented strand board/waferboard.*

Table 145.—Wood product use factor indexes for housing alteration and repair, nonresidential construction, manufacturing and shipping, 1986, with projections to 2040.

Year	Softwood lumber	Hardwood lumber	Structural panels
		(1986 = 100)	
		Housing alteration and repair[1]	
1986	100	—	100
2000	100	—	111
2010	105	—	113
2020	105	—	117
2030	105	—	120
2040	100	—	124
		Nonresidential construction[2]	
1986	100	—	100
2000	100	—	127
2010	100	—	103
2020	100	—	108
2030	100	—	112
2040	100	—	115
		Manufacturing[3]	
1986	100	100[4]	100
2000	80	74	95
2010	74	57	89
2020	69	42	85
2030	67	39	80
2040	65	18	76
		Shipping[3]	
1986	100	100	100
2000	61	83	82
2010	45	79	66
2020	35	68	62
2030	27	57	63
2040	24	46	66

[1]*An index of board feet (or squar feet) per household per year.*
[2]*An index of board feet (or squar feet) per constant dollar of construction.*
[3]*An index of board feet (or square feet) per unit of the Federal Reserve Board index of manufacturing output.*
[4]*An index of board feet per unit of furniture production.*

Wood Product Use in Manufacturing and Shipping

Manufacturing and shipping consume more lumber and panel products than for any use except new residential construction. Manufacturing, as defined here, includes production of furniture, other wood products made for sale,[52] and wood products used in various production processes. Shipping includes pallets and skids, wooden containers, and dunnage, blocking, and bracing. In 1986, an estimated 72% of all hardwood lumber consumed was for manufacturing and shipping (7.3 billion board feet). Lesser volumes of softwood lumber (4.3 billion board feet), and structural panels (1.6 billion square feet, 3/8-inch basis) were also consumed. Nonstructural panel consumption for manufacturing and shipping was 44% of total consumption in 1986 (8.0 billion square feet 3/8-inch basis) (table 21). Nonstructural panels include hardwood plywood, hardboard, insulating board, particleboard, and medium density fiberboard.

Improvements in manufacturing and shipping technologies have the potential to decrease or increase wood consumption. Technology changes may decrease wood use by enabling producers to use less wood in manufacturing process, in finished products, and in packaging and shipping of the finished products. Other technology changes may increase wood use by permitting substitution of wood parts for nonwood parts, by requiring more wood per unit output, or by opening new markets for wood products. Technology changes may also extend timber supply by allowing products to be made from trees, logs and lumber of previously unused species, sizes or grades.

Furniture and pallets are the largest users of wood in manufacturing and shipping. In 1986 furniture production used 43% of the lumber used in manufacturing, and pallets used 93% of the lumber used in shipping (tables 11 and 12). These products have traditionally been large users of hardwood lumber. Half of all lumber used in furniture, and more than three-fourths of all lumber used for pallets is hardwood (McKeever and Martens 1983, McKeever et al. 1986, McCurdy et al. 1988).

The production of furniture, and, to an increasing extent, the production of pallets, tends to be highly mechanized. Adoption of new technologies by furniture and pallet manufacturers can hold down timber demand by reducing the amount of wood used per unit of output. Selected technologies likely to affect furniture and pallet production are discussed below.

Possible Changes in Furniture Production

There are several technology developments which may reduce the wood needed to make a given furniture part, or reduce the proportion of high grade lumber needed to make a given set of parts. Technologies being developed could increase the efficiency of the breakdown of hardwood lumber and, to a lesser extent softwood lumber, to make furniture parts. These technologies are the Automated Lumber Processing System (ALPS) (McMillin et al. 1984), and YIELD-O-MATIC. ALPS and YIELD-O-MATIC are in the basic development stage, and are not expected to be commercially available for more than 10 years. Both systems will increase both lumber recovery value and volume. Growth and improvements in existing technologies such as edge, end and finger jointing; computer assisted cross and rip sawing; and better finishing of less desirable species are now increasing both lumber recovery value and volume. Other technologies such as computer numerical control of woodworking operations in furniture plants will lower costs by speeding production, improving accuracy, and using labor more efficiently.

[52]*Includes sporting goods, musical instruments, boat-building and repair, toys and games, luggage and trunks, handles, wood pencils, mortician's goods, shoe and boot findings, wooden matches, commercial refrigeration, signs and displays, patterns and jigs, truck bodies and trailers, general machinery, agricultural implements, electrical equipment, and textile machinery supplies.*

Technology improvements in structural and nonstructural panel processing will increase the substitution of panels for lumber, and the substitution of nonstructural panels for structural panels. As a result, demand will increase for hardwood veneer and panels using paper overlays. These two types of substitution will reduce the demand for medium-to-high grade hardwood lumber, and will hold down timber demand generally as a greater proportion of product volume uses more efficient panel making techniques to convert logs to products.

Other factors affecting the use of lumber and wood products for furniture include changing consumer preferences for wood versus nonwood furniture, particularly for higher value furniture, the relative cost of producing furniture from wood verses other materials such as steel, and the competition from foreign producers. We expect increased use of nonwood materials in low-to-middle quality furniture, and relatively constant use of wood in high value furniture. Foreign trade in unassembled wood furniture and parts is expected to increase.

Projected Wood Use Rates in Furniture Manufacturing

The overall impact of technology changes and other factors on wood use in furniture manufacturing are summarized in table 145. Overall, hardwood lumber use per unit of furniture production is expected to fall over the next 50 years even though use may increase for high value furniture. The decline will be caused by several factors, including technology changes that increase the efficiency of lumber conversion to furniture parts, substitution of panels for lumber, substitution of nonwood materials for wood in low-to-middle quality furniture, and increasing imports of unassembled wood furniture. Softwood lumber and structural panel use are also expected to decline, but not as much as hardwood lumber. This is because the relative lower cost of these products makes substitution of other nonwood products less profitable. Nonstructural panel use is expected to increase.

Possible Changes in Pallet Production and Use

The pallet industry is the single largest consumer of lower grade hardwood lumber. One-third to one-half of all hardwood lumber is used for pallets. Pallets have traditionally been a means for sawmills to use the lower grade lumber they produce. They produce one or two types of pallets using little or no automated equipment. Today up to half of all pallets are produced using nailing machines and a limited number of producers have large, modern facilities with automated sawing, lay-up, and nailing, and a large product line. There is great potential for raw material savings through increased use of these new sawing and pallet construction techniques.

The greatest potential for saving wood in pallets is from increased use of new computerized pallet design systems. Pallets have traditionally been designed to support the heaviest possible load. This results in excessive lumber use. Computerized pallet design systems permit producers to quickly change pallet design based on the type of load. More efficient lumber use will result as the pallets are better matched to their loads.

Wood use in pallets may also be affected by a shift from reusable to expendable pallets. Expendable pallets will use less wood per pallet, but due to a shorter life, more will be produced. Reusable pallets require more wood but last longer, especially with repairs. Another shift that could save large amounts of wood would be the salvage and repair of reusable pallets. Salvage and repair is expected to increase with increasing costs of pallet production and disposal of damaged pallets. Mechanical pallet dismantlers will make pallet repair operations more profitable.

Lumber consumption in pallets may also decrease as more composite materials are used in pallets. Pallet decks made from structural panels provide a flatter, more uniform surface than lumber decks. Pallets made from molded particleboard can be custom made to meet the specific transportation needs of products.

Growth in pallet production is also expected to be held down with increasing competition from substitute materials-handling products, such as plastic slip sheets, and from increasing saturation of industries that can use palletized shipping.

Projected Wood Use Rates for Shipping

The overall impact of technology change and other factors on wood use for shipping are shown in table 145. Hardwood lumber use in shipping per unit of manufacturing output is expected to decrease over the next 50 years. The decrease will be caused by several factors, including technology changes that increase the efficiency of lumber use in pallets, substitution of panels for lumber, a trend towards greater re-use of damaged pallets, and increased use of pallets made from nonwood materials. Use of oriented strand board and waferboard in shipping per unit of manufacturing output is expected to increase as it becomes an acceptable substitute for lumber decking. Softwood lumber and plywood use are also expected to decline with the rapidly declining use of wooden containers in favor of paper and plastic, and the virtual elimination of wood use for dunnage, blocking, and bracing during transportation. A small increase is expected in the use of nonstructural panels.

Wood Use for Energy

Wood, together with bark, is most widely converted into energy by direct combustion in many types of burners. Black liquor, a woodpulp byproduct, is also used to produce energy at pulp plants. Some wood or black liquor is used to produce electricity in cogeneration plants. Technology is also available, although not always economical, to (1) convert wood to gas by thermochemical gasification and burn it in boilers, driers, and kilns or internal combustion engines; (2) convert wood to synthesis gas for manufacture of liquid fuels such as methanol, or chemical feedstocks; (3) convert wood to gas, liquids and solids (such as charcoal) by pyrolysis; and (4) convert wood to other liquid fuels such as ethanol by hydrolysis and fermentation.

Recent and future technology improvements in converting wood to energy will improve wood energy's competitive position relative to alternate fuels and increase wood energy use. Technology improvements will also improve the efficiency of wood conversion to energy and tend to hold down wood demand for energy.

With decreasing fossil fuel supplies and environmental and economic problems in the use of other alternatives such as nuclear energy, there is an overall tendency for increased use of wood for energy. Wood use for energy has both environmental benefits and costs. Unlike much coal and some petroleum, wood has little or no sulfur and appears less likely to produce oxides of nitrogen during combustion. Therefore wood burning emissions are less likely to contribute to the production of acid rain. This is in contrast to fossil fuels which increase atmospheric carbon dioxide content and may cause damage because of the greenhouse effect (Zerbe and Skog 1988). However, caution must be used to prevent excessive removal of biomass in forest harvests to avoid nutrient depletion or increased potential for soil erosion. Wood burning may have other environmental costs. Combustion of wood in inefficient combustors without proper controls adds smoke and particulate emission to the air. This problem has resulted in development of residential wood stove performance regulations by the U.S. Environmental Protection Agency which limit particulate emissions. There has also been concern about proper combustion of wood contaminated with other materials such as paint, adhesives, and/or preservatives.

Improved wood conversion technology may make wood for energy more competitive, even with oil prices increasing more slowly than anticipated. But, a major factor in using more wood for energy is high cost of forest harvesting. It is prudent to use wood for energy that is less valuable and less suited for use in other consumer products. However, the lower value wood is often from smaller trees that are more expensive to harvest. Harvesting is also more expensive for lower density stands and stands that have a higher proportion of hardwoods rather than softwoods.

While harvesting of small trees for fuel may be expensive, increased use of logging residue may be an inexpensive way to aid in forest management. In public and private forests under management for timber production and other purposes, there are significant management costs from cleanup after logging operations. Often brush from logging operations is broadcast-burned to prepare land for new tree growth. This is costly and subjects the atmosphere to more particulate loading. On some national forests in California, broadcast burning is avoided through cleanup credits for harvesting excess wood for energy. In some areas of California, dense brush in forests at urban-forest interface areas is being successfully harvested for energy, thereby significantly decreasing the fire hazard to houses at the forest perimeter.

Possible Changes in Technology

Use of wood for energy may be divided into three roughly equal categories of consumption. These are residential wood burning, black liquor burning, and industrial wood waste/roundwood burning. Lesser, but growing, amounts of wood are consumed in power generation and commercial and institutional applications.

For residential use of wood for energy the traditional approach has been roundwood consumption in fireplaces or simple stoves. Fireplaces are inherently inefficient and are more esthetic than utilitarian. However fireplaces are being used more efficiently with newer technology developments in the control of makeup air and hot air distribution, and in the use of better designed insert units (stoves) for fireplace spaces. Stoves are also being designed to use roundwood more efficiently with better control of air for combustion.

A newer development in residential wood burning is the combining of improved fuels with improved combustion units to attain more efficient and more automatic operation. Fuels may be made more efficient, cleaner burning, and easier to handle by control of size and moisture content. Examples are dried chips and pellets. A new product is chunkwood which comes in larger size particles, and may be more efficient to produce, handle, and store. More sophisticated stoves and furnaces have been designed to take advantage of improved fuels such as pellets.

In industrial applications, older boiler technologies such as the Dutch oven and traveling grate are still operating satisfactorily, but new technologies including the fluidized bed and gasification are providing advantages in combustion and emission control. Promising developments for industry in the future are a gravel bed combustor; new technology for gas, liquid, and char fuels; and burning wood in combination with coal.

Development of a pressurized gravel bed combustor may allow wood to be used to power gas turbine engines, primarily for generation of electricity. Advanced industrial and utility power systems often use gas or liquid-fueled gas turbine engines. They burn fuels directly in a turbine, without going through an intermediate heat exchanger to heat air for use in the turbine. This is an efficient means of generating electricity. Using coal or wood combustion gases to directly power a gas turbine has yet to be accomplished commercially, primarily because the ash can cause erosion, deposition, and corrosion of the turbine blades. The size, distribution, concentration, and composition of the ash, as well as the turbine design, determine the lifetime of the turbine blades. New direct combustion turbines using pressurized gravel bed combustors to alleviate these problems are under development (Ragland and Baker 1987). Successful completion of this work could make wood power generation in the range from 10 MW to 50 MW more competitive.

Improvements in converting wood to gas, liquid and char fuels are possible. If wood is to become a viable, more general replacement for oil as oil becomes more expensive, wood needs to be used in ways other than as a boiler fuel and residential space heating fuel. Wood may be converted to liquid and gaseous fuels and to improved forms of solid fuel such as charcoal. Technology is available to make ethanol from wood at a cost comparable to making ethanol from corn, but this technology is only economical with a large subsidy in today's market. The current large federal subsidy which sets the pattern for state subsidies is scheduled for elimination by the end of 1992, and a more competitive liquid fuel is needed to compete in later years. Provision of gaseous fuel from wood can be achieved with known technology, but the cost of gas derived from wood is much higher than the cost of natural gas (Zerbe 1988).

Gasification and pyrolysis research may lead to more economical liquid fuels from wood such as methanol, pyrolysis oils, or conventional gasoline. For the near term, development of a viable methanol from wood process is realistic to expect. Other potential products are gas for operation of internal combustion engines, turbines, and lime kilns, and pyrolysis oils for diesel fuel.

Wood may be increasingly burned along with coal in industrial boilers. Federal regulations stipulate that for coal boilers with capacities of 100 million Btu/hr or more, the particulate emission limit is 0.05 lb/million Btu heat input if coal is burned alone; but if coal is cofired with wood, the limit is raised to 0.1 lb/million Btu heat. Emission limits for sulfur dioxide and oxides of nitrogen from combustion of coal and wood are based on total heat input, no matter what the fraction of wood used. These regulations provide an incentive to burn wood in combination with coal in large boilers, particularly in the case of high sulfur coals (Dykes 1988).

Projected Efficiency in Conversion of Wood to Energy

The preceding discussion suggests many ways that the demand for and efficiency of residential and industrial wood burning may change. The projections of wood energy use given in table 107 resulted in part from the influence of the changes discussed here. The projections in Chapter 7 assumed that the efficiency of industrial/commercial wood burning will increase at the same rate as for fossil fuels between 1985 and 2040. For residential wood burning between 1985 and 2000, the efficiency of wood and fossil fuel burning was assumed to increase, but the increase in fuel oil efficiency will be somewhat faster than for wood or natural gas. After 2000, all fuels were assumed to increase in efficiency at the same rate (tables 93 and 94).

RESEARCH AND CHANGES IN WOOD UTILIZATION TECHNOLOGY

The first two sections of this chapter discussed historic trends and prospective future trends in wood utilization technology. This section discusses the linkage between research, technological change in industry, and various economic benefits, especially changes in timber consumption and prices. The questions we address are: (1) What are the key influences on research, development and adoption of new technologies and resulting technology change? (2) How effective has past wood utilization research and resulting technology change been in creating various benefits? and (3) How effective might selected current areas of Forest Service research be in changing technology and altering timber consumption and prices?

Key Influences on Research, Development, and Adoption of New Technology

Several influences are particularly important for the forest products industry in determining the course of research and development, and the pace of adoption of new technology. These include (1) innovations imported from other industries, (2) the effect of raw material shortages, (3) the effect of economic performance of innovations, (4) problems in developing and using innovations for a heterogeneous raw material, and (5) problems in developing and using innovations for heterogeneous final products.[53]

Innovations Imported from Other Industries

Prospects for technological change in forest products are heavily influenced not only by commitment of resources to research and development within public and private institutions focused on the industry but also by developments that are remote from forest products. A study for 1974 found that lumber and wood products firms were the expected main user of $67 million (1974 dollars) of R&D performed in other industries and $64 million of R&D performed inside the industry (Scherer 1982).[54] The highest dollar value of other industry research used was in industries making machinery, motor vehicles and equipment, paints and other chemical products, and fabricated metal products (75% of $64 million). For the pulp and paper sector, the figures were $120 million and $86 million, respectively. The dollar value of other industry research used most heavily was in industries making machinery, paints and other chemical products, synthetics/resins/fibers/rubber, and computer and office equipment (55% of 120 million).

One example of use of outside technology in forest products industries has been the considerable use of sophisticated electronic components, including computers and lasers, for quality control of processing and products. The extent to which new outside technologies will be applied to forest products will depend upon the

[53] *Material for this section is selected from a study report by Nathan Rosenberg (1988) for the USDA Forest Service, Forest Products Laboratory.*

[54] *Excludes innovations developed by government and university laboratories.*

rate at which those technologies experience reductions in their own costs of production as well as improvements in their performance and versatility. In this respect, the future of the forest products industry is influenced by forces largely beyond its own control. Improved monitoring and evaluation of developments in other domestic industries and foreign industries could speed development and transfer of technology to U.S. forest products industries.

The Effect of Raw Material Shortages

Technology change in forest products industries although influenced by outside technology developments is also strongly influenced by the structure of raw material costs within the industry, and more broadly by the structure of costs for all manufacturing inputs and the prices of products competing with forest industry products. Here, because of our interest in timber resources, we focus on the response to raw material scarcity. The industry has an advantage in being able to predict with some confidence the trend in availability of logs of various sizes in a region 20 years ahead. But forecasting a response, including a technology response, to a particular timber trend may be difficult.

Public and private research are responsive to expectations concerning future availability of various types of timber and will develop research programs to counter the scarcity. Increasing scarcity of an input, and the associated rise in its price, calls into play a wide range of more immediate economic and social adjustments—simple conservation measures, changes in design of products, and substitution of products using more abundant materials. Technology response may include technological changes that reduce costs by reducing labor and capital requirements, or substitute more abundant for scarcer inputs (e.g., capital for material), or reduce the quantity or quality of wood input per unit of output. For example, increasing scarcity of saw logs in recent decades has encouraged use of a technology that uses smaller logs and lower quality timber in general. Also, the sharp increase in veneer log prices in the early 1970s undoubtedly spurred the expansion of waferboard/oriented strand board production which uses lower cost wood input. Expected long range and short range trends in raw material scarcity and associated trends in labor and capital scarcity, while being key influences on technology change, induce a wide range of adjustments which require a detailed analysis to sort out.

The Effect of Economic Performance of Innovations

Decisions to develop and to adopt new technologies are ultimately based upon economic performance and not purely technological considerations. Seemingly superior technologies may be adopted slowly because, when all costs are taken into account, they are not decisively cost-reducing in their impact. Most distinctly new technologies do not constitute just a slight modification in a single dimension of an existing technology. Rather, they represent clusters of new characteristics, some of which are positive and some of which are negative. Development and commercialization involves a sorting out process, in which negative features are reduced while positive ones are enhanced. One example is promising new mechanical pulping technologies, which hold out the prospect of higher yield, but are burdened with the requirement of higher energy costs (Ince 1987). The speed of adoption of innovations will turn heavily upon the nature of the positive and negative features and their relative ease of malleability. In many cases this situation gives rise to a long and costly period of development activity. When commercial introduction of an innovation is contemplated, costly new equipment is often required. Therefore, the introduction is likely to be associated with replacement of depreciated equipment or establishment of new mills. In either case, required special market conditions for inputs, or access to favorable financing may long delay introduction.

In the forest products industry there is a particular institutional feature that may significantly influence the timing of the adoption decision. Substantial research is currently done in the public sector, by the USDA Forest Products Laboratory, regional Forest Service research stations, and state universities. But commercial success usually requires more research, development, and demonstration than can be attained by a public agency. That is, fine tuning product design and characteristics to user needs, as well as further process and machinery improvements may be needed. Therefore, the final push in making improvements and adoption has to come from the private sector and must await the stimuli of changing prices or costs that ordinarily influence private firm decisions. These stimuli may be particularly important to large corporations that may be more resistant to change (Blair 1972).

After initial commercial adoption, a technology's technical and cost performance continues to change. The first application of a new technology is typically crude in comparison to characteristics eventually attained. Although this feature is shared with other industries, it may assume greater importance in forest products where improvement from one generation to the next may be slower because of difficulties in acquiring information about harvesting, processing, and using wood of widely varying properties.

Problems in Using Innovations for a Heterogeneous Raw Material

The forest products industry, if not unique, is at least at the extreme end of a spectrum of possibilities with respect to the variety of inputs that it employs in its different productive processes. Wood is an organic material with a remarkable degree of natural diversity and versatility which reflects a range of conditions: species of tree, age, location, growing space, climate, moisture, position in the tree, etc. Such heterogeneity complicates the process by which useful knowledge is accumulated and diffused within the industry. Research findings in aluminum, iron and steel, pharmaceuticals, or electronics have the potential for some immediate wider degree of generality, but the situation is very different for forest products. The behavior of wood is highly variable not only from one species to another, but even from one location in a log to another. Many of the difficulties of the industry in developing and applying innovations result from the fact that technological problems are often too subtle and too multivariate for scientific methodology to offer general guidance. It is not that the necessary information cannot be obtained, but that each relatively small "bit" of information typically has to be acquired at a slow pace and at a high cost. Furthermore, scientific information, once obtained, cannot be readily used in other contexts involving other species, subspecies, or locations. It is this inherent difficulty in the information acquisition process, and not the mature stage of the industry, that accounts for the difficulties in bringing scientific methodologies more effectively to bear upon the industry's technical problems. A major thrust of research and technological change in the industry has been to overcome these effects of input heterogeneity.

Problems in Using Innovations for Heterogeneous Products and Product Use Conditions

The heterogeneity of wood input leads directly to heterogeneity in characteristics of wood products. In addition, when placed in use, wood products face a wide range of demanding use conditions. In wood-based construction, for example, every final product, even after grading, is to some degree unique, and its required performance is unique because of the specific environment where it is used. A consequence of having heterogeneous outputs, plus long life of products in construction, is that it takes an unusually long time to sort out the contributions of separate variables on product performance. One major thrust of research and technological change in the industry is to make products of relatively uniform performance characteristics from heterogeneous inputs. Many innovations have involved taking a diversity of low quality timber and converting it into more reliably performing products with lumber-type, or plywood-type characteristics. Examples are laminated veneer lumber, parallel strand lumber, waferboard and oriented strand board. Problems of acquiring information about performance is similar for the pulp and paper sector. It may take years to clarify something as elementary as the energy requirements associated with a new pulping technology, partly because of heterogeneity among wood inputs and partly because of the varied performance requirements of the pulp.

The Impact of Past Research

Having discussed several important influences on the course of research, and development and adoption of innovations, we turn to more specific discussion of the actual effectiveness of research, development, and technology transfer efforts. In general, successful research and technology transfer efforts lead to technology change that has been shown to be a major component of economic growth and development. New technologies can create new industries, replace old products with new ones, and, in many ways, improve processes which provide goods and services. The role of public and private research in generating technical change has been examined extensively during the past several decades, and the link between investment in research and productivity growth has been repeatedly demonstrated in empirical studies (Mansfield 1972, Evenson et al. 1979, Griliches 1987).

Similarly, forest products research and resulting technology change have been major forces influencing timber resource utilization. Changes in species availability and growing stock have been accommodated by changes in forest products technology, thus averting severe dislocations and scarcity. "As preferred species, sizes, and qualities of wood have become depleted due to increased demand, processing technologies have been adjusted to work with more abundant species and materials previously thought to be unusable" (U.S. Congress OTA 1983, p. 130).

The sweeping changes in wood utilization technology in recent decades suggest that the economic impacts of forest products research have been substantial. Until recently, however, there has been no empirical evidence to support this notion. Table 146 summarizes the results of recent economic evaluations of wood utilization research, categorized as either aggregate or case study evaluations. Aggregate studies examine the relationship between investment in research and productivity growth in an entire industry or sector of the economy. Innovation case studies focus on the impacts of specific new technologies produced by a research effort.

Aggregate Evaluations

Haygreen et al. (1986) evaluated the impacts of seven major timber utilization technologies. They compared actual research expenditures to projected benefits (net savings of timber value) due to technology adoption. Even with a very conservative assessment of benefits and liberal estimate of costs, the calculated rate of a return on the investment in forest products research is 14–36%.

Seldon (1987) used an econometric modeling approach to estimate returns[55] of research conducted to produce softwood plywood in the South. He explained the high internal rates of return—in excess of 300%—mainly by the fact that public softwood research was applied research that was quickly adopted by softwood plywood producers.

Seldon and Hyde (1989) applied Seldon's (1987) econometric modeling approach to the U.S. softwood

[55]*Returns included estimated savings to consumers in the form of lower product prices and savings to producers in the form of lower production costs.*

Table 146.—Economic evaluations of wood utilization research.

Study	Research evaluated	Time period	Measures of economic impact Marg. IRR(%)[1]	Avg. IRR(%)	B/C Ratio
Aggregate evaluations					
Haygreen et al. (1986)	Timber Utilization	1972–2000		14–36	
Seldon (1987)	Softwood plywood	1950–80	+300		
Seldon & Hyde (1989)	Softwood lumber	1950–80	5–30	13–47	
Brunner & Strauss (1987)	Wood preserving	1950–80			15/1–66/1
Bengston (1985)	Lumber & wood products	1942–73		34–40	
Innovation case studies					
Bengston (1984)	Structural particleboard	1950–2000	27–35	19–22	
Mansfield et al. (1977)	Paper innovation	1960–73		82	

[1]*IRR = internal rate of return.*

lumber industry for the period 1958–80. Average internal rates of return of public research in this area ranged from 13% to 47% over this period, depending on several assumptions. Marginal IRR ranged from 5% to 30%.

Brunner and Strauss (1987) evaluated the economic benefits of public research and development in the U.S. wood preserving industry. Technical change in this industry involved innovations in chemical preservatives, new treatment methods, and new methods for conditioning wood prior to treatment. Using the evaluation method developed by Seldon (1987), Brunner and Strauss found significant social benefits[56] stemming from this public research. Over the period 1950 to 1980, the net present value of research benefits amounted to between $7.5 and $17.7 billion (1982 dollars) depending on several assumptions, and benefit-cost ratios ranged from 15 to 66.

Bengston (1985) estimated the rate of return to investments in U.S. lumber and wood products research from 1942 to 1973 to be 40%.[57] Recognizing that technical change in the lumber and wood products industry depends in part on innovations developed in other industries, the costs of interindustry technology flows were included in the analysis. After adjusting for the flow of technology changes from other industries, the rate of return was calculated at 34%.

Innovation Case Studies

Bengston (1984) estimated the return[58] on investment in public and private research which led to the manufacture of oriented strand board/waferboard. Oriented strand board/waferboard is a reconstituted wood panel with properties suitable for structural and exterior applications. This major innovation has a significant impact on timber utilization in North America because it uses relatively abundant soft or low density hardwoods rather than scarce softwood species. Using an economic surplus model, estimated rates of return from investment in oriented strand board/waferboard research range from 19% to 22%. Estimated marginal rates of return ranged from 27% to 35%, suggesting that even higher investments in this type of research would have produced even more attractive returns.

Mansfield and others (1977) evaluated an innovation in paper manufacture—a new paper product that cut costs for users—in an evaluation of 17 industrial innovations. They estimated the social and private returns[59] from research and development that generated these innovations. The social rate of return to research leading to the paper innovation was estimated to be 82%. The private rate of return was found to be 42%, indicating that the benefits from this innovation were shared between consumers and the innovating firm.

Conclusions

These studies confirm that many types of utilization research have significant economic returns. Some studies suggest the returns are higher than for other public forestry investments such as public nonindustrial private forest incentives or public forest timber management investments (Boyd and Hyde 1989). Utilization research has been a highly attractive investment compared to public investments generally—the social rate of return to utilization research is substantially above the return obtainable from most other public investments, which typically range from 5% to 15%. This is some evidence of an underinvestment in utilization research. An optimal level of investment is one where the returns to all investments are equal at the margin, i.e., the returns to added research investments are equal to returns on other investments (given equal levels of risk). Higher levels of investment in utilization research would be justified if, after adjusting for different risk, return on additional investment is above the average return for other public investments.

[56]*See note 55.*

[57]*Returns included estimated savings to producers in the form of lower production costs.*

[58]*Returns included estimated savings to consumers in the form of lower product prices.*

[59]*Returns included estimated savings to consumers in the form of lower product prices and selected returns to inventors.*

The Impact of Selected Areas of Current Forest Service Research

The previous section indicates how past utilization research leads to benefits in the form of lower costs to consumers for products, and/or lower production costs for producers. In this section, to more closely evaluate the potential effect of research on the adequacy of future timber supplies, we evaluate how selected current U.S. Forest Service research may, in association with other research, development, and technology transfer efforts, change future timber consumption and prices. Because of our focus on the timber market consequences of research we do not evaluate many other important potential benefits of utilization research, such as improved worker or consumer safety, or environmental protection.

To conduct this evaluation, seven areas of Forest Service research were identified which, if successful, would influence prices and consumption in timber markets. These areas ranged from basic research on certain pulping processes, to applied research on timber harvesting, to technology transfer efforts to improve lumber and plywood/veneer production. The research areas are as follows:

1. Harvesting,
2. Lumber and plywood/veneer processing,
3. Design and performance of wood structures,
4. Development of improved adhesives from renewable resources,
5. Expanded use of timber bridges,
6. Development of new or improved composite products using wood, and
7. Pulp, paper, and paperboard processing.

Scientists at the USDA Forest Service, Forest Products Laboratory (FPL) and other regional forest research stations identified how successful completion of research-development-adoption efforts would alter timber processing or demand for timber products. For many research areas, we assumed complementary research and development would be done by universities and/or industry. For each research area (other than pulp, paper, and paperboard) scientists described how research would alter such technical factors as product recovery factors, processing costs, or rate of wood use in various end-products, as well as the timing of such changes. These expected technology changes were translated into sets of changes (one set for each research area) to the base case assumptions used to make timber market projections to 2040 with the Timber Assessment Market Model (TAMM) and the Hardwood Assessment Market Model (see Chapter 7). We use 'TAMM' to refer to both models. The sets of changes were used to make separate simulation runs to project timber market conditions that reflect successful completion of each research area. Finally, we compared TAMM projections of timber and wood product consumption and prices between the base case and the altered cases. For research area 7—pulp, paper and paperboard—we used the FPL Pulpwood Model. Scientists estimated technical characteristics (pulp yield and cost) of new ways to make various grades of paper, and the timing of their commercial introduction. These new processes were inserted in the FPL Pulpwood Model to alter projections of pulpwood and paper/paperboard production and prices (Howard et al. 1988). Altered projections of pulpwood and selected paper/paperboard price and production were compared to the base case. Altered projections of pulpwood consumption were then inserted in the TAMM model and the resultant saw timber and solid product projections were compared to the TAMM base case.

The first section below explains the research being conducted in each area and the resultant anticipated technology changes as implemented in TAMM or the FPL Pulpwood Model. The section on findings explains the potential impact of the research areas in terms of differences in timber and wood products prices, differences in harvest/consumption levels, and differences in total annual product value (price times volume) between the base case and altered projections.

Harvesting

We evaluated two kinds of Forest Service harvesting research in terms of their potential impact on softwood saw timber/veneer log harvesting: (1) research to transfer analyses and ideas about which types of existing equipment are best to use in various situations, and (2) research to improve equipment and systems efficiency with new types of hardware or new designs. To implement the effect of the first research activity, we increased the pace of change in the mix of harvesting systems used (see harvesting section above and Bradley 1989). We assumed the base case system mix for the year 2001 would be achieved by 2000. To implement the effect of the second research activity, Forest Service harvesting researchers estimated how cost efficiency could be improved in various equipment systems by 2040 with continued research by the Forest Service, universities, and industry. We assumed the Forest Service would produce about one-third of the efficiency gains (in rough proportion to research expenditures). The combined effect of the two research activities, after accounting for projected changes in stand density and stem diameter, is estimated to reduce harvesting cost 5–7% by 2040 in various U.S. regions.

Lumber and Plywood/Veneer

We evaluated three Forest Service activities that will improve lumber and plywood/veneer processing: the IMPROVE program, research to use Best-Opening-Face (BOF) concepts for hardwood lumber production, and research to develop the Automated Lumber Processing System (ALPS) for hardwood lumber. IMPROVE is a technology transfer program to develop and distribute a series of personal computer programs for sawmill, veneer, and plywood industries for improving product output and profitability from existing operations. Applying BOF concepts to hardwood lumber will increase overall lumber recovery and grade recovery from hardwood logs. Research on ALPS is intended to: (1) develop tomography and computer software for internal defect detection and breakdown of logs, (2) develop computer vision and computer control for cutting lumber into furniture parts, and (3) develop lasers to cut lumber into furniture parts.

We estimate the IMPROVE program would speed up improvement in softwood lumber and plywood recovery, and reductions in processing costs. The program would also help increase hardwood lumber recovery, as described later in this report. As a result of such acceleration, we assume improvements formerly estimated to occur by 2001 would occur by 2000. By 2000, softwood lumber and plywood recoveries would improve an extra 0.3% and 0.5%, respectively, and processing costs would decrease an extra 0.5% and 0.1%, respectively.

With successful completion and adoption of BOF research to make hardwood lumber, as well as efforts in the IMPROVE program, we estimate that overall hardwood lumber recovery would increase at a rate of 1.6% per decade between 1985 and 2000, and 1.5% per decade between 2000 and 2040. In the base case, hardwood lumber recovery would increase 1.0% per decade.

ALPS would increase recovery of higher hardwood lumber grades by using tomography to scan for internal defects and computers to aide in breakdown. With use of this technology, we estimate 10% of the lumber formerly graded as less-than-1-common would move to 1-common, and 10% of the lumber formerly graded as 1-common would move to higher grades. We assume this technology would be used for 25% of lumber production by 2040. ALPS would also decrease the amount of lumber needed to produce a given quantity of furniture parts by using computer vision and computer controlled conventional or laser cutting. We assume computer vision would initially reduce lumber use per unit of furniture parts by 10% in 1995, expanding to 15% by 2040. By 2040, we assume 50% of furniture parts production would use the technology.

Design and Performance of Wood Structures

The Forest Service is engaged in 10 research activities that will improve the design and performance of wood structures. These include:

1. Development of more reliable engineered wood structural components such as wooden I-beams,
2. Improved design criteria for efficient and reliable structural connectors,
3. Accurate determination of effects of use conditions on structural components,
4. Improved resistance of wood products and assemblies to fire,
5. Improved techniques for rehabilitating wood structures,
6. Development of advanced design procedures to improve competitiveness of designs using wood relative to designs that use steel or concrete,
7. Improved adhesive-connected structural components,
8. Accurate assessment of structural lumber properties (aids in using advanced design concepts),
9. Flexible and precise nondestructive evaluation techniques to aid grading of lumber, and
10. Development of stress class/species independent grading to enhance use of diverse species.

We judged that success in these research activities would increase lumber and panel use for nonresidential structures, and decrease lumber use and increase panel use per square foot of residential construction. For nonresidential structures, we assume that by 2010 and thereafter the research will increase lumber, plywood, and oriented strand board/waferboard use by 15% over levels in the base case by increasing the number of buildings where wood is used. This increase accounts for the fact that advanced design procedures will reduce the wood used per square foot of floor area. For single- and multifamily homes, we assume this research will accelerate technology changes projected to occur at a slower pace in the base case. For single-family homes, lumber use will decrease 15% because of more efficient design (by 2010 rather than 2040), and structural panel thickness will increase (to provide needed strength with wider stud spacing) in floors, wall sheathing and siding by an average of 7.5% to 12% by 2010. For multifamily homes, lumber use in floors will decrease slightly and average floor panel thickness will increase. Lumber use in roofs and walls is already quite efficient. The aggregate effect of research on design and performance of wood structures will be to increase both lumber and structural panel consumption above levels in the base case projections.

Adhesives From Renewable Resources

Adhesives developed from renewable resources, particularly tree components, may be important because they may be cheaper than petroleum-based phenolics if oil prices increase substantially. The availability of adhesives from renewable resources may hold down the cost of structural panels, especially oriented strand board. If adhesives from renewable resources are not available, and if oil prices roughly double to $50 per barrel (1982 dollars) by 2020, we estimate increases in phenolic adhesive prices would increase plywood prices by 5–16% and oriented strand board prices by 46% by 2020. Availability of economical adhesives from renewable resources would hold down such panel price increases.

Expanded Use of Timber Bridges

The Forest Service has undertaken a program to promote use of timber to replace thousands of smaller bridges in the United States each year. Roughly one-quarter million bridges are in need of eventual repair or replacement. Currently, less than 1,000 timber bridges are built each year. With improved economical designs, we estimate that the annual construction of timber bridges could be increased to 7,500 bridges by 1995 and continue at that level through 2040. An average bridge would use 1,300 cubic feet of wood, for a total of 9.75 million cubic feet per year. We estimate that between 1995 and 2040, the West would produce an extra 60 million board feet per year of softwood lumber/timber for bridges, and the East produce an extra 30 million board feet of both hardwood and softwood lumber/timber. This extra production would be 0.19% and 0.33% of 1986 softwood and hardwood lumber production, respectively.

New or Improved Composite Products

Forest Service research on composite wood products includes development of steam injection pressing to form panels, chemical treatments to improve dimensional stability and water resistance of composite panels, and composites of wood and nonwood materials (e.g., plastics) for many applications.

We assume that chemicals will be injected by steam injection pressing in oriented strand board-type products to make them dimensionally stable and suitable for exterior use in construction. Specifically, treated oriented strand board will be used more widely for concrete forms in construction and for wood foundations, siding, and exterior millwork for single-family housing. We assume that by 2040 (1) treated oriented strand board will largely substitute for plywood in foundations and concrete forms, (2) treated oriented strand board will substitute for some plywood in single-family housing and will slightly expand the market, and (3) treated oriented strand board will substitute for about half the lumber millwork in exterior applications. These changes amount to a relatively small shift from plywood and lumber to oriented strand board-type products compared to the base case.

Research on composites of wood and nonwood materials could yield products that pair wood with nonwood biomass, metal, plastics, glass, or synthetic fibers. Much current research is devoted to wood-plastic composites. These composites could substitute for existing wood products such as packaging (containers, cartons, pallets) and decrease wood use, or they could substitute for nonwood products such as auto and truck components and increase wood use. We assume wood-plastic composites will have the widest use, and will, overall, tend to increase wood use. We use wood-plastic composites in auto or truck components as a proxy to indicate the overall net increase in wood use. Wood use in such composites would be 3.6 million cubic feet by 2040, assuming 15% wood use in 30% of such auto or truck components. This increased consumption is small compared to 1987 wood consumption of 18.7 billion cubic feet.

Pulp, Paper and Paperboard

We evaluated five areas of Forest Service pulp, paper, and paperboard research: improved mechanical pulping of hardwoods to make linerboard, and printing and writing paper; peroxymonosulfate pulping for cheaper, less polluting pulping of hardwoods; techniques to increase or improve wastepaper recycling; production of newsprint from 100% hardwoods; and development of Spaceboard I (a replacement for corrugated boxboard). Anticipated developments in these areas were used to make 18 changes in the way 8 grades of paper and paperboard are made in the FPL Pulpwood Model (Howard et al. 1988).

Research on mechanical pulping for hardwoods in linerboard could lead to use of pulp with yields of 85% to 95% compared to levels of 50% to 55% for conventional unbleached kraft pulp. The research may provide a means to make linerboard from 100% hardwoods with 80% yield by the year 2015—specifically, chemithermomechanical pulping (CTMP) with press drying to form paperboard. Mechanical pulping could also increase the use of hardwoods in making printing and writing papers. Research on mechanical pulping is oriented toward reducing energy consumption, increasing paper strength, and, for printing and writing grades, maintaining optical properties as needed, reducing color reversion, and achieving high brightness.

By 2010, research on peroxymonosulfate pulping may facilitate the increased use of hardwood in newsprint, unbleached kraft paperboard, solid bleached paperboard, printing and writing papers, packaging and industrial papers, and tissue. Peroxymonosulfate pulping may be able to produce a relatively high-yield pulp from 100% hardwoods that has improved bonding strength and higher brightness relative to other hardwood pulps. Peroxymonosulfate pulp could be used in combination with other pulps to make many grades of paper.

By 2010 to 2015 research on wastepaper recycling may facilitate additional increases in use, or altered use, of recycled paper for newsprint, unbleached kraft paperboard, solid bleached paperboard, recycled paperboard, printing and writing paper, packaging and industrial paper, and tissue. To increase recycling, research is being done in the following areas: development of a disk separation process to separate contaminants from recycled fiber, improvement of means to remove contact and noncontact ink from printing and writing papers, and development of chemical and biological treatments to restore bonding strength to recycled paper fibers.

Research on CTMP and biomechanical pulping (BMP) with press drying may be successfully combined to make newsprint from 100% hardwoods. Mills using CTMP/press drying, or BMP/press drying may be possible beginning in 2015 and 2025, respectively. Combining CTMP with press drying may achieve higher sheet strength previously attainable only with softwoods. Bleaching may be needed when using certain hardwood species. Combining BMP with press drying has the possibility of increasing strength and also retaining optical properties for more hardwood species (low and medium density species).

Research may provide a new product, FPL Spaceboard I, that would replace some corrugated fiberboard to make boxes (Setterholm 1985). Spaceboard is a sandwich of two or more pulp-molded structures. The structures have a flat surface on one side and a structural waffle-like rib pattern on the other. The structures are glued together, rib to rib, to form a structural board. Spaceboard could be made with several kinds of fiber. We assume that manufacturing plants for Spaceboard I, located near large cities, will be built by 2000 and will use 100% recycled corrugated containers as raw material. We estimate Spaceboard I may replace 25% of corrugated container board by 2040.

General Findings

As we have described, the objectives of wood utilization research are diverse. They serve a wide variety of interest groups, including forest landowners, loggers, product producers, and consumers. To conduct a welfare analysis that would identify a complete range of welfare gains and losses for all forest sector interests is beyond the scope of this study. (For an example of such an analysis see Adams et al. 1977.) Nevertheless, the limited set of measures used in our study clearly show that the interest groups who gain and lose vary from one research area to another. The approach used here is similar to one used by Skog and Haynes (1987) to evaluate past wood utilization research.

To measure market impact, we used the change in timber and wood product prices, harvest/consumption volume, and harvest/consumption deflated dollar value (1982 dollars). These measures clearly indicate gains or losses for some groups. For example, stumpage price increases or harvest volume increases that lead to increased value of harvest are a gain to landowners, whereas price increases for final products are a loss for consumers. But these measures do not clearly indicate gains or losses for producers. For example, a decrease in lumber price caused by reduced cost of timber may lead to a profit gain for producers, but a decrease in lumber price caused by reduced demand for lumber may lead to a profit loss.

For all research areas, change in price, harvest/consumption, and value were estimated for softwood and hardwood saw timber, softwood and hardwood lumber, softwood plywood, and oriented strand board/waferboard. These estimates were produced using TAMM model projections.[60] For pulp, paper, and paperboard research, change in price of softwood pulpwood, and change in production of softwood and hardwood pulpwood and selected grades of paper and paperboard were estimated. These estimates were made using the FPL Pulpwood model.

In terms of the magnitude of impact, the research areas fall into three groups. Research on harvesting, lumber and plywood/veneer, timber bridges, and composite products cause less than 5% change in price, harvest/consumption, and value through 2040. Research on design and performance of wood structures and development of adhesives from renewable resources may change the price or consumption of some products by 5–20% by 2040. Research on pulp, paper, and paperboard may decrease softwood pulpwood consumption by 36% by 2040. A key difference between the first two categories and pulp and paper research is that the full effect of research in the first two categories is expected well before 2010, whereas the effect of pulp and paper research will not begin until 2010–2020. The six research areas (except for pulp, paper, and paperboard) are expected in the long run to lead to higher softwood saw timber prices; and with the exception of adhesives and pulp, paper, and paperboard research, to higher softwood saw timber harvest.

The percentage of change in softwood saw timber prices caused by the alternate research areas is generally greater than the change in harvest volume. This is because stumpage supply is not very responsive to price changes and solid-wood product demand is not very responsive to product price changes. As a result, the increase in softwood saw timber value caused by research in categories 1 and 2 is caused primarily by increases in stumpage price and not increases in harvest volume.

The potential decreases in pulpwood harvest volume resulting from pulp, paper, and paperboard research are much larger than any potential increase in saw timber harvest resulting from any of the research areas. The potential 36% decrease in pulpwood harvest by 2040 is equal in volume to 30% of the projected softwood saw timber harvest in 2040.

The potential decreases in harvest value—both for pulpwood and saw timber—resulting from pulp, paper, and paperboard research are much greater than any potential increase in saw timber harvest value caused by other research areas. The potential annual value decrease in pulpwood alone would exceed $1.4 billion by 2020, and $3 billion by 2040. The associated annual value decrease for softwood saw timber could be $0.2 billion by 2020, and $3.2 billion by 2040.

Findings for Specific Research Areas

Harvesting research, by holding down softwood saw timber harvesting costs, would increase lumber consumption and softwood saw timber production by a few tenths of a percent over the projection period, and increase softwood saw timber price by up to 4.2%. The annual value of softwood saw timber harvest increases by up to 4.6% ($413 million in 2030). Lower harvest cost reduces lumber prices and overall value for softwood lumber consumption by up to 0.9% by 2040. The price and consumption of plywood and oriented strand board/waferboard vary above and below the base case as variation in relative prices causes substitution between panels and lumber.

Lumber and plywood/veneer research and technology transfer raise softwood lumber and plywood conversion efficiency and lower manufacturing costs through the year 2000. Efficiency improvements result in a near-term

[60] *To try to avoid observing the effects of technology differences on short-term business cycles generated in TAMM, we compared average price and consumption levels between the base case and altered cases. Averages were taken for 9-year periods around 2000, 2010, 2020, and 2030.*

reduction in softwood saw timber price and harvest, and a slight increase in lumber production. In the long run, lower manufacturing costs increase saw timber harvest, price, and value. The annual value of saw timber harvest increases by up to 2.3% (in 2030). Higher timber costs lead to higher lumber prices, lower production levels, and lower lumber value (by 0.4% in 2040), a counterintuitive result. Research on hardwood lumber leads to higher hardwood lumber conversion efficiency and less lumber use per unit of furniture production. This results in lower hardwood saw timber and lumber consumption, prices, and value. The value of hardwood saw timber and lumber decrease by 2.0% and 2.7%, respectively, by 2040. The price, consumption, and value of plywood and oriented strand board/waferboard vary above and below the base case as variation in relative prices causes substitution between panels and lumber.

Research on design and performance of wood structures increases consumption, prices, and value for softwood saw timber, lumber, and plywood, as would be expected. The value of softwood saw timber, lumber, plywood, and oriented strand board increases by 7.0%, 3.1%, 6.2% and 5.0%, respectively, relative to base case projections by 2040. Hardwood saw timber and lumber prices remain relatively unchanged because hardwood lumber demand is not altered (table 147).

Research to produce adhesives from renewable resources would keep down the price of adhesives as petroleum-based products increase in price. This would keep oriented strand board/waferboard prices as much as 20% lower, and plywood prices as much as 3.9% lower. These estimated price effects are greater than could actually be achieved because we assumed in our analysis that the new adhesives could keep glue prices constant at current levels. Because of the price inelasticity of demand for panels, a much lower oriented strand board/waferboard price (held down by cheaper glues) would result in only 2% higher production. Plywood production with cheaper adhesives will be lower than in the base case. This is because oriented strand board/waferboard will be in a relatively stronger competitive position with cheaper glue than in the base case. With lower glue costs, the annual value of panels consumption is $831 million less by 2040. Much of this will be saving of glue costs. The combined annual value of softwood plywood and oriented strand board is lower by 4.6% and 22.8%, respectively, by 2040. With lower glue costs there is higher timber demand for panels, saw timber and lumber prices are higher, their harvest/consumption is lower, and their change in value is mixed over time (table 147).

The expanded use of timber bridges increases saw timber harvest by roughly 0.2% and 2.5% for softwoods and

Table 147.—Potential impact of research on engineered structures and adhesives, on price, production level, and value of various types of timber and wood products in the future.

Market characteristic and product	Design and performance of structures					Adhesives from renewable resources				
	2000	2010	2020	2030	2040	2000	2010	2020	2030	2040
	Percent difference from base case projection[1]									
Price[2]										
SW sawtimber	3.1	5.6	6.0	7.4	6.8	0.2	0.9	*	1.5	1.2
HW sawtimber	*	-0.1	*	0.1	0.1	*	0.1	0.2	0.4	0.6
SW lumber	0.9	1.1	1.3	1.9	1.4	0.2	0.5	-0.2	-0.3	0.1
HW lumber	*	*	*	0.1	0.1	*	0.1	0.2	0.3	0.4
SW plywood	1.0	2.1	3.5	0.9	6.0	-1.8	-3.4	-3.5	-3.8	-3.9
OSB/waferboard	0.2	-0.8	0.5	-0.2	-0.1	-10.0	-15.0	-20.0	-19.0	-19.0
Harvest/consumption[3]										
SW sawtimber	0.3	0.5	0.1	0.3	0.1	*	-0.1	-0.2	-0.4	-0.6
HW sawtimber	*	*	*	-0.1	*	*	*	-0.1	-0.1	-0.2
SW lumber	0.7	1.4	1.5	1.6	1.7	-0.1	-0.2	-0.1	*	0.1
HW lumber	*	*	*	*	*	*	-0.1	-0.1	-0.1	-0.2
SW plywood	0.7	1.0	0.9	1.0	0.2	-0.6	-1.2	-1.4	-0.9	-0.5
OSB/waferboard	2.3	4.5	4.7	4.8	5.0	1.3	2.0	1.6	1.1	0.8
	Value difference in millions of 1982 dollars[1]									
Value										
SW sawtimber	183	461	539	701	664	-13	-54	13	-100	-59
HW sawtimber	-1	-6	0	0	6	0	-3	-8	-18	-29
SW lumber	278	520	654	817	740	-27	-68	64	73	-32
HW lumber	0	3	2	4	3	0	0	7	13	21
SW plywood	67	137	204	93	331	-94	-211	-238	-249	-246
OSB/waferboard	37	71	110	104	127	-134	-304	-473	-513	-585

**Value is between -0.05 and 0.05.*
[1]A positive value indicates the altered case is greater than the base case.
[2]Sawtimber prices are for stumpage. Other prices are for delivered products.
[3]Sawtimber volume is for U.S. harvest. Other volumes are for amounts consumed in the United States. Net imports from Canada may change and are included.